CLOSED CYCLES & THE CIRCULAR SOCIETY

THE POWER OF ECOLOGICAL ENGINEERING

12TH IEES CONFERENCE

BOOK OF ABSTRACTS

Organized by

TECHNICAL UNIVERSITY OF CRETE

IEES

LABORATORY OF ENVIRONMENTAL ENGINEERING AND MANAGEMENT

WELCOME MESSAGE

It is our pleasure to publish the Book of Abstracts of the 12th international conference of the International Ecological Engineering Society "Closed cycles and the Circular Society 2023: The power of ecological engineering", organized in Chania, Greece between 1-5 October 2023.

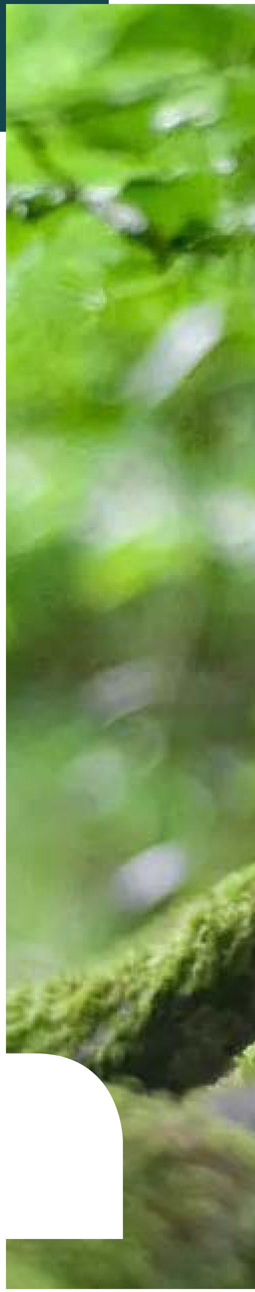
Our Laboratory of Environmental Engineering and Management at the Technical University of Crete was honoured to host and organize this event in Chania on the island of Crete and bring the conference series in Greece for the very first time.

This conference is special for our Society as it marks the 30th anniversary since the foundation of the IEES in 1993!

It is now the time and our wish to deliver and spread the message of redefining the ecological engineering discipline and communicate our vision of an ecology-inspired engineering, as declared in our Manifesto of Ecological Engineering.

In this booklet you will find useful information about the conference such as:

- ✓ The structure of the conference program, following the session titles
- ✓ All conference abstracts, presented in a way that follows the conference format



The Book of Abstracts is available on the conference website
http://www.iees.tuc.gr/

CONFERENCE CHAIRS

Asst Prof Dr Alexandros Stefanakis

President of the International Ecological Engineering Society

Dr Andreas Schoenborn is Lecturer and Researcher at the Institute of Natural Resource Sciences, School of Life Sciences and Facility Management, Zurich University of Applied Science - ZWACH in Switzerland. He is also Head of the Ecological Engineering Group.

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Topics

- Use of ecological elements and ecosystems to reduce pollution
- Use of ecosystems in a circular society
- Circular design and integrated planning approaches for increased resiliency
- Resource recovery and reuse
- Climate change, green and just transition, and carbon neutrality: the role of ecological engineers
- Regenerative agriculture
- Ecological Engineering and the mining industry
- Ecological Engineering Education

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Thank you!

THE INTERNATIONAL ECOLOGICAL ENGINEERING SOCIETY

https://iees.ch

The IEES was founded in 1993, with the idea to bring together experts and conduct Ecological Engineering activities within an international society.

IEES is a non-profit organization seeking to promote and advance a broad view of Ecological Engineering (working definition of IEES) through:

1. Connect
Facilitate and improve the cooperation between ecologists, engineers and other scientific fields

2. Exchange
Promote the exchange between scientific and educational organizations, enterprises, and (non-) governmental organizations

3. Educate
Support the development of a common Ecological Engineering curriculum

4. Promote
Raise the awareness of Ecological Engineering practice worldwide

OUR HISTORY

The idea to bring together experts and conduct Ecological Engineering activties within an international society was born at the 1st Conference on Ecological Engineering in Stensund, Sweden in 1991.

The Stensund Ecological Center with its ‘Vattenbruket’, a Wastewater Aquaculture greenhouse demonstrating Ecological Engineering principles of closed nutrient cycles served as a unique crystallization point.

Two years later, in October 1993 the society was officially founded in Utrecht, Netherlands by thirteen engaged participants. The first annual meeting was held in June 1994 in Stangvik, Norway. Since then the network has been spanning widely around the globe with its headquarter today located in Switzerland at ZHAW Wädenswil.

IEES BOARD (2023 - TODAY)

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OUR MANIFESTO OF ECOLOGICAL ENGINEERING

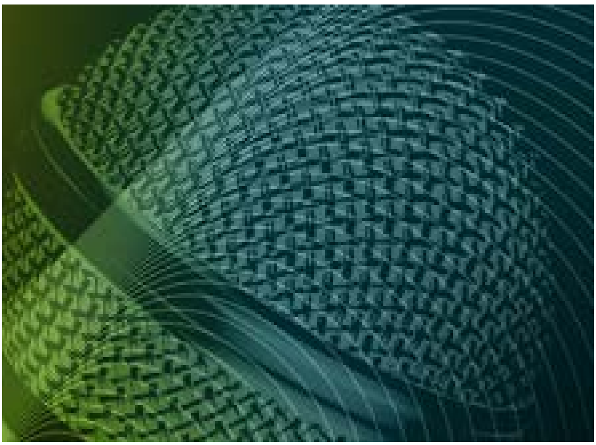
https://iees.ch/our-manifesto/

The planetary ecosystem today faces significant **environmental challenges**, such as climate change and the **unsustainable** use of resources that may have disastrous and irreversible **impacts** at local and global scale.

These threats to the very existence of our global society indicate that we **urgently** need **new approaches** to deal with these rising challenges.

In order to cope with these, we need to **fundamentally** change the way we **think**, the way we approach modern environmental problems and the way we **make decisions** and develop solutions.

We are dealing with **multi-dimensional**, complex and interrelated issues, which render **ineffective** the conventional one-dimensional linear, technology-focused approach to problem-solving.



Engineering and **ecology** have crucial roles to play in solving many of these global issues. For this, a new **design paradigm** for engineering is now a necessity to support the transition to a truly sustainable society.
We are convinced that **systems thinking** is the first critical step towards the development of new holistic and interdisciplinary engineering solutions at all scales.
We are convinced that an ecology-inspired approach to engineering provides answers to these challenges.
We view the inherent value of nature as **part**, not only of future solutions, but also of the design process itself.
Ecological engineering integrates ecological principles, processes, and organisms with the existing engineering practice, forming a new, **holistic** approach for problem-solving.

Ecological engineering **reshapes** engineering solutions, not just to minimize waste output but to design out waste, **restore** the ecological functions and **eliminate** the unwanted impact of all processes and interventions.
Ecological engineering adopts **circularity** in problem-solving methodology by re-establishing **cycles of materials** to deal with resource scarcity.
Ecological Engineers view nature as an **inspiration** and model to develop and expand the **nature-based** toolbox, using ecosystem services and renewable resources.
Ecological Engineers work **with nature** for the **benefit** of society and the environment and see people and civil society as an integral part of this new problem-solving approach.
As an independent **worldwide group** of professional engineers and scientists, Ecological Engineers work to create a more resilient, sustainable and equitable global ecosystem for all.
We address this call to the global community for a change to make the world a better and safer place through **awareness** and action in ecological engineering for environmental **resilience**, social **responsibility** and sustainable **development.**

IEES 2023 PROGRAM

Closed cycles and the Circular Society 2023: The power of ecological engineering
1-5 October 2023, Chania, Greece

Sunday 1 Oct		Grand Arsenal (Chania old port)	
	17:30	Registration desk open	
	18:00 - 20:00	Welcome reception	

O = Oral presentation: 10 min talk + 4 min Q&A + 1 min buffer (Speaker change)
F = Flash Oral presentation: 4 min talk + 1 min buffer (Speaker change)

Monday 2 Oct		IMPERIAL MAIN HALL	IMPERIAL ROOM 1	IMPERIAL ROOM 2
	08:00 - 09:00	Registration (lobby area)		
	PLENARY SESSION I Chair: Alexandros Stefanakis			
	09:00 - 09:15	CONFERENCE OPENING AND WELCOME Alexandros Stefanakis, IEES President		
	09:15 - 09:30	WELCOME MESSAGES Professor Michalis Zervakis (TUC Rector) Ioannis Malandrakis (Mayor of Platanias Municipality)		
	09:30 - 10:15	KEYNOTE: Nature-based Solutions for Wastewater Treatment and Application of Circular Economy strategies Fabio Masi (Iridra Srl, Italy)		
	10:15 - 10:45	Coffe break (lobby area)		
		Session A1: Circularity in the built environment Chair: Mateus Dina & Schubert Hendrik	Session A2: Social dimension of NBS Chair: Pagano Alessandro & Johannes Heeb	Session A3: Resource recovery from water Chair: Raffael Känzig + Gajewska Magdalena
	10:45 - 11:00	(O-099) A spatial perspective on circular economy and the construction sector within Flanders (Belgium) Pisman Ann (Belgium)	(O-030) Methodological approach for assessing the effectiveness of co-creation processes of Nature-based solutions: The case-study application of CLEVER Cities project. Mahmoud Israa (Italy)	(O-040) Production and recovery of orthophosphate from phosphonate-contaminated wastewater combining ozonation and ultraviolet advanced oxidation processes Ji Yuxian (Belgium)
	11:00 - 11:15	(O-021) Valorisation of the stabilized organic fraction of mixed municipal waste as building materials within a circular economy Santos Michael M. (Portugal)	(O-112) Why there are not more Nature-Based Solutions implemented in European cities: A Stakeholder Analysis Pineda-Martos Rocío (Spain)	(O-119) Framework elaboration for the development of hybrid modelling for resource recovery from municipal wastewater and impact mitigation in Gotland/SE *(R)* Francisco Erika Cristina (Sweden)
	11:15 - 11:30	(O-014) Formalising the temporal aspect of timber component reusability in a circular construction indicator Anastasiades Kostas (Belgium)	(O-087) The use of Participatory System Dynamics Modelling to support 'Nexus doing': preliminary results from the Koiliaris (Greece) case study Pagano Alessandro (Italy)	(O-044) Exploring the potential of cyanobacterial microbiomes for sustainable bioproducts Joan Garcia (Spain)
	11:30 - 11:45	(O-135) Waste to construction: A novel Hempcrete product research Meir Isaac (Israel)	(O-152) Multi-criteria tool for Nature-based Solutions and Bioeconomy practices selection towards WEFE Nexus implementation: the case of Tinos island Tsatsou Alexandra (Greece)	(O-048) Electrocoagulation flotation treatment technology in perspective of resource recovery and reuse of municipal wastewater in different regions of the world Hassan Nazia (Belgium)
	11:45 - 12:00	(O-096) Why edible cities? Regelsberger Martin (Austria)	(O-163) Tiganokinisi: social innovation though the collection and recycling of domestic used cooking oil in Cyprus Petsa Demetra (Cyprus)	(O-134) Sidestream sulphide-driven denitrification as robust solution to enable resource recovery in a large-scale industrial WWTP Polizzi Cecilia (Italy)
	12:00 - 12:05	(F-016) Plant-based biocides for the sustainable conservation of built heritage – Field experiments Mateus Dina (Portugal)		
	12:05 - 12:10	(F-034) Advancing circular economy in the built environment: The CircularB Action Pineda-Martos Rocío (Spain)	(O-009) Combining public participation, participatory design and AI to promote integrated planning approaches Dyer Mark (New Zealand)	(O-069) Recovery of resources and generation of valuable products from municipal wastewater – assessment of products quality Krzeminski Pawel (Norway)
	12:10 - 12:15	(F-057) Biomimicry in architectural design in a holistic design process Nowak Anna (Poland)		
	12:15 - 13:45	Lunch time!		
		Session A4: Novel designs of Constructed Wetlands Chair: Uggetti Enrica & Jan Vymazal	Session A5: The impact of urban NBS on public health and well-being Chair: Kolokotsa Dionysia & Mahmoud Israa	Session A6: Circular design for increased resilience I Chair: Filippos K. Zisopoulos & Goonetilleke Ashantha
	13:45 - 14:00	(O-104) The Integrated constructed wetland design approach: A review Harrington Rory (Ireland)	(O-008) On the integration of nature-based solutions for health and wellbeing in two European Cities: The case studies of Dundalk and Skelleftea Kolokotsa Dionysia (Greece)	(O-083) Bioregional approach for circular design: case study in Roma via Guido Reni (Italy) Francese Dora (Italy)
	14:00 - 14:15	(O-095) Efficiency removal of specific substances in multistage treatment wetland for urban drainage water Gajewska Magdalena (Poland)	(O-110) Measuring the impact of Nature-Based Solutions on citizens' health and well-being: risks and challenges of using wearable devices Biesaga Mikołaj (Poland)	(O-085) El Remanso experimental center in Choachí-Colombia, A laboratory Eco-Village to learn and co-build Rojas Hector (Mexico)
	14:15 - 14:30	(O-100) Removal performance of different types of bioelectrochemical constructed wetlands for dairy wastewater treatment Kotsia Dimitra (Greece)	(O-088) Greenness visibility in urban living environments as pathway to promote health and well-being: mapping spatial differentiation in Flanders (Belgium) based on viewshed analysis Vervoort Peter (Belgium)	(O-185) Advancing sustainability in industrial supply chains by embracing circular approaches and digital transformation Maria Aryblia (Greece)
Knowledge Transfer Event (lobby area) ---------------- SEALIVE ---------------- Strategies of Circular Economy and Advanced bio-based solutions to keep our Lands and seas alIVE from plastic contamination ---------------- ISOTECH Ltd AKTI Project & Research Center SEALIVE	14:30 - 14:45	(O-171) Performance of pilot-scale constructed wetlands with different designs and substrates treating olive mill wastewater Dimitra Moschogianni (Greece)	(O-151) Urban greenery's effects on public health and wellbeing of citizens and how to assess it – preliminary euPOLIS findings Randelovic Anja (Serbia)	(O-162) Eco-traditional buildings in Makkah: Al-Byaddiah Palace as a case study Faredah Almurahhem (Saudi Arabia)
	14:45 - 14:50	(F-052) Floating constructed wetlands based on recycled polymers to restore aquatic ecosystems López Daniela (Chile)		
	14:50 - 14:55	(F-009) Selecting innovative substrates materials: characterization and potential application for enhancing CWs sustainability Ventura Delia (Italy)	(O-155) Innovative urban solutions to enhance public spaces and promote good public health and wellbeing - the case studies of euPOLIS and VARCITIES Randelovic Anja (Serbia)	(O-184) Advancing Sustainability of Process Industries through Digital and Circular Water Use Innovations – Experience from AquaSPICE project Arampatzis Goerge (Greece)
	14:55 - 15:00	(F-017) Smart monitoring of waste-filled constructed wetlands for the removal of nutrients from wastewater with low carbon content Pinho Henrique (Portugal)		
	15:00 - 16:00	Coffe break (lobby area) & Poster session		
		Session A7: Sludge management Chair: Alexandros Stefanakis & López Daniela	Session A8: Sustainable Drainage Systems Chair: Frank van Dien & Tsatsou Alexandra	Session A9: Circular water economy Chair: Simos Malamis & Tjasa Griessler Bulc
	16:00 - 16:15	(O-032) A pilot study of domestic sewage sludge dewatering using Sludge Treatment Reed Beds in Oman Al-Rashdi Tahra (Oman)	(O-076) Blue-green infrastructure in highly urbanized areas - practical design examples Rous Vit (Czech Republic)	(O-159) Water companies and circular economy : Challenges and opportunities Kotsifaki Christina (Greece)
	16:15 - 16:30	(O-133) Sludge Treatment Constructed Wetland: a solution for treating sewage sludge for agricultural reuse Uggetti Enrica (Spain)	(O-150) Sustainable drainage systems (SuDS) for rainwater harvesting and stormwater management in temporary humanitarian settlements Tota-Maharaj Kiran (United Kingdom)	(O-114) Water recovery in swimming pools in accordance with the assumptions of the circular economy Kudlek Edyta (Poland)
	16:30 - 16:45	(O-173) DIALKOP project: design and operation optimization of Sludge Treatment Reed Beds in Greece Ioannis Asimakoulas (Greece)	(O-149) Experimental study and nodelling of granular filter nedia used within SuDS for stormwater purification Tota-Maharaj Kiran (United Kingdom)	(O-153) Water quality monitoring of recycled water using effect-based bioassays – a tool for the circular economy Schoenborn Andreas (Switzerland)
	16:45 - 17:00	(O-067) Fate of pit latrine sludge buried in entrenchments Bakare Babatunde Femi (South Africa)	(O-023) Assessment of the potential for microplastic retention in mature SUDS Calzadilla Cabrera Dario (Spain)	(O-136) Greywater treatment and reuse in a residential building in Zurich, Switzerland: Evaluation of the treatment performance and user acceptance Vischer Tabea (Switzerland)
	PLENARY SESSION II Chairs: Alexandros Stefanakis & Raffael Känzig			
	17:00 - 17:45	30 years of IEES (all participants invited!)		

Tuesday 3 Oct		IMPERIAL MAIN HALL	IMPERIAL ROOM 1	IMPERIAL ROOM 2
	08:30 - 09:00	Registration (lobby area)		
		Session B1: Resource recovery and reuse from waste Chair: Antonopoulou Georgia & Ashley Hall	Session B2: Green roofs and walls Chair: Michael Ruby & Pineda-Martos Rocío	Session B3: Sustainable management of waste biomass Chair: Asli Isci Yakan & Timo Steinbrecher
	09:00 - 09:15	(O-124) Development of a beach management technology solution to monitor and mitigate plastic marine littering Tzanetou Dimitra (Greece)	(O-144) If you build it, they will come: invertebrates on green roofs Michael Ruby (Australia)	(O-027) Deep eutectic solvent pre-treatment of residual biomass streams - effects on anaerobic degradability Schultz Jana (Germany)
	09:15 - 09:30	(O-066) Turning a nuisance into a resource: options and obstacles for sustainable use of beach wrack derived from case studies Schubert Hendrik (Germany)	(O-128) Proposing a holistic experimental setup for green roof flammability testing Chell Sylvie (Australia)	(O-053) Transforming biogenic waste through anaerobic digestion in achieving the circular economy Fan Chihhao (Taiwan)
	09:30 - 09:45	(O-138) Location-based resource analysis tool for waste management and makers: a case study of Pop-Machina Conserva Andrea (Spain)	(O-168) On the influence of plant morphology in the extensive green roof cover: a case study in Mediterranean area Sara di Lonardo (Italy)	(O-089) Deep eutectic solvent pretreatment of cork dust: effects on biomass composition, phenolic extraction and anaerobic degradability Bagder Elmaci Simel (Turkey)
	09:45 - 10:00	(O-157) 3D printed Mn-based monoliths for lithium recovery from oilfield brines Knapik Ewa (Poland)	(O-158) Novel computational tool for coupling water and heat transport models – application on green roofs Stanic Filip (Serbia)	(O-093) Potential applications of hazelnut industry waste based on material properties Aguado González Laura (Spain)
	10:00 - 10:05			(F-005) Wool of mountain sheep - maximizing resources utilisation Kobiela-Mendrek Katarzyna (Poland)
	10:05 - 10:10	(O-010) Reusing depleted hydrocarbon reservoirs: An ecological alternative? Bauer Johannes Fabain (Germany)	(O-078) Performance of three ornamental species for indoor living walls irrigated with greywater Pérez-Urrestarazu Luis (Spain)	(F-029) Wheat bran proteins – raw material for production of nutritional-valued food Slavíková Zuzana (Czech Republic)
	10:10 - 10:15			(F-004) Application of sheep wool as slowly released organic fertilizer in tomato and winter wheat cultivation Broda Jan (Poland)
	10:15 - 10:20	(F-046) Energy-efficient bipolar membrane electrodeionization for integrated water and chemical recoveries from wastewater of recycled polyethylene terephthalate processes Lin Yu-I (Taiwan)		(F-008) Integrated chemicals and waste management for reduction of adverse effects to environment Aleksandryan Anahit (Republic of Armenia)
	10:20 - 10:45	Coffe break (lobby area)		
		Session B4: Urban and regenerative agriculture Chair: Argüello Jazmin & Broda Jan	Session B5: Bioenergy, Renewable energy systems and energy efficiency Chair: Kolokotsa Dionysia & Stergios Vakalis	Session B6: Circular design for increased resilience II Chair: Nowak Anna & Ann Pisman
	10:45 - 11:00	(O-098) Urban agriculture in Latvia – is that a choice between business, community networking and individual traditions? Dobele Madara (Latvia)	(O-130) Carbon neutrality of energy produced from woody biomass Jandl Robert (Austria)	(O-061) How circular design and integrated planning approaches may increase resiliency and biodiversity? Adam Avshalom M. (Israel)

	11:00 - 11:15	(O-115) Linking nature, culture, and food as an urban farming nature-based solution Argüello Jazmin (France)	(O-071) An innovative approach towards energy conservation using single RGB camera technology for obtaining occupant location in buildings Jeoung Jaewon (South Korea)	(O-011) Regenerative economics for assessing and monitoring transitions towards a circular economy Zisopoulos Filippos Konstantinos (Netherlands)
	11:15 - 11:30	(O-132) HABSIM – Unique R&D Infrastructure for closed-loop food production in space and on Earth Blomqvist Tor (Germany)	(O-072) Sustainable solutions under climate change towards water and energy independence using wind power and hydrogen storage Bertsiou Maria Margarita (Greece)	(O-052) Voluntary standards, as a way how the food industry and retailers control impact of their supply chains on ecosystem services provided by soil Frouzova Jaroslava (Czech Republic)
	11:30 - 11:45	(O-146) Fighting poverty of West African fishermen through aquaponics training centre in Kokrobite, Ghana Kaenzig Raffael (Switzerland)	(O-118) Design and implementation of a solar thermal system as a contribution to resilience and sustainable development in paramo ecosystems Kafarov Viatcheslav (Colombia)	(O-097) Measurement scale validation for inner and outer circular economy loops: a proposal based on food and beverage circular packaging and wishcycling Vayona Anastasia (United Kingdom)
	11:45 - 11:50		(F-013) Recovery of bioenergy and high added value bioproducts from confectionary industrial wastewaters Ntaikou Ioanna (Greece)	
	11:50 - 11:55	(O-103) Urban bioeconomy: mapping organic resource streams and the bio-symbioses in cities through Geospatial and Material Flow Analysis Yang Nan-Hua Nadja (United Kingdom)	(F-018) Coupling retired electric vehicle batteries with PV systems for urban sustainability: the case study of Greece Kastanaki Eleni (Greece)	(O-183) It is a waste to waste waste: examples of circularity in Kenya and Mali (just listen to your grandfather) Ruud Kampf (Netherlands)
	11:55 - 12:00		(F-021) Renewable resources in the conditions of the Slovak Republic Daneshjo Naqib (Slovakia)	
	12:00 - 12:05	(F-038) Analysis of the aquaponics system sustainability via system dynamics modelling – FEW nexus approach Francisco Erika Cristina (Sweden)	(F-020) Effect of environmental factors on dust accumulation and the efficiency of photovoltaic panels: A study case in an Andean City Sanchez Nazly (Colombia)	(F-003) Training a new generation of farmers and agricultural entrepreneurs to implement the concept of circular economy in agriculture – the TANGO-Circular Erasmus plus project George P. Spyrou (Greece)
	12:05 - 12:10	(F-064) Analysis of selected factors determining the possibility of introduction and effective operation of rainwater sharing systems for hydroponics in existing multi-family buildings Bąk Joanna (Poland)	(F-045) Forest conversion and GHG emission in screening and EIA procedures regarding PV sys-tems in Croatia Kalcicek Matea (Croatia)	(F-065) Towards sustainable food systems deploying Circularity Compass Strategy Papadopoulou Kyriaki Maria (Greece)
	12:10 - 12:15	(F-056) Close cycle approach in a food farm in Reggio Emilia, Italy Romagnolli Floriana (Italy)	(F-048) Implementation of DSS to optimize the selection of marine energy sites on the Mexican coastline Rivera Camacho Graciela (Mexico)	(F-067) Development of a blockchain solution for food waste management Plakas George (Greece)
	12:15- 12:20	(F-022) Optimization of wheat nutrition for regenerative agriculture Sadovski Alexander (Bulgaria)	(F-049) Osmotic power generation-based System for self-consumption electricity Ortiz Salcedo Monserrat Karina (Mexico)	
	12:20 - 14:00	**Lunch time!**		
	14:00 - 14:45	**KEYNOTE:** Nature-based solutions to optimize the Water-Ecosystem-Food Nexus at the basin scale Nikolaos Nikolaidis (Technical University of Crete, Greece)		
		Session B7: Stormwater management **Chair: Polizzi Cecilia & Henrique Joaquim de Oliveira Pinho**	**Session B8: Constructed wetlands applications** **Chair: Giuseppe Cirelli & Ioannis Asimakoulas**	**Session B9: Ecological restoration** **Chair: Zhang Mingye & Schoeman Yolandi**
	14:45 - 15:00	(O-057) Nature-Based Solutions for flooding risk mitigation in an urban area: The case study of Catania (Sicily, Italy) Sciuto Liviana (Italy)	(O-013) Assessing the treatment capacity of an ecological engineered wetland receiving AMD over a period of nine years using water quality and periphyton as indicators Oberholster Paul Johan (South Africa)	(O-051) The role of natural processes in post mining land reclamation Frouz Jan (Czech Republic)
	15:00 - 15:15	(O-165) Adoption of ecohydrology approaches for urban stormwater management and advancing the circular economy concept Goonetilleke Ashantha (Australia)	(O-172) Efficiency of pilot scale constructed wetlands with various substrates for landfill leachate treatment Ioannis Asimakoulas (Greece)	(O-073) Phytocap soil density specification for optimum plant water use and root growth Ruby Michael (Australia)
	15:15 - 15:30	(O-019) Advancing Nature-Based Solutions for the management of water quality under the umbrella of the UNESCO IHP Ecohydrology Programme: case study of Pilica river catchment in Poland Jarosiewicz Paweł (Poland)	(O-074) Use of Vertical Flow Constructed Wetlands for domestic laundry wastewater treatment with ornamental plants Stefanatou Aimilia (Greece)	(O-033) Organic amendments-based technosols for the restoration of Mediterranean habitats and soil-carbon sequestration Carabassa Vicenç (Spain)
	15:30 - 15:45	(O-101) Science behind STORMEE - STORMwater Environmental Efficiency toolkit: 1) infiltration basin Vasilic Zeljko (Serbia)	(O-043) Small constructed wetland in Norwegian agricultural catchment – 18 years monitoring and perspectives for the future Krzeminska Dominika (Norway)	(O-045) Ecological engineering enhances ecological restoration in Chinese desertified lands Xinrong Li (China)
	15:45 - 15:50	(F-019) Sub-calibration of soil moisture sensor for stormwater management Perry Joseph (Finland)	(F-037) Life cycle assessment of Horizontal Subsurface Flow Constructed Wetlands: The importance of regional characteristics to enhance environmental protection Goulart Coelho Lineker Max (Denmark)	(F-023) Significance of soil type and applied fertilization on the content and uptake of macroelements with sunflower biomass Petkova Zdravka (Bulgaria)
	15:50 - 16:30	**Coffe break (lobby area) & Poster session**		
		Session B10: NBS for climate change adaptation **Chair: Nikolaos Nikolaidis & Dimitra Kotsia**	**Session B11: Water quality improvement for resource efficiency** **Chair: Darja Istenič & Pawel Krzeminski**	**Session B12: Ecological engineering for the protection of land and biodiversity** **Chair: Carabassa Vicenç & Joan Garcia**
	16:30 - 16:45	(O-169) CARDIMED - Climate Adaptation and Resilience Demonstrated In the MEDiterranean region Simos Malamis (Greece)	(O-077) Degradation of organic micropollutants in a modified OECD 308 test: implications for the use of reactive amendments in nature-based systems Perdana Mayang Christy (Czech Republic)	(O-164) Integrating the scope of ecological engineering applications: A structured framework with case studies from Australia Dale Glenn (Australia)
	16:45 - 17:00	(O-050) Development of a climate change adaptation plan for the Jordan Valley based on WEFE nexus analysis: The EcoFuture project Nikolaos Nikolaidis (Greece)	(O-020) Degradation of perfluoroalkyl and polyfluoroalkyl substances (PFAS) in secondary effluent by nonthermal plasma: role of reactive oxidative and reductive species Chen Changtao (Belgium)	(O-160) Field application of processed biosolids: Integrating municipal waste management and regenerative agriculture in Canada Grant Clark (Canada)
	17:00 - 17:15	(O-143) A glimpse into the euPOLIS multi-dimensional indicator system for site screening & NBS assessment Baki Sotiria (Greece)	(O-179) Techno-Economic Feasibility Analysis (TEFA) of the Advanced Primary Filtration (APF) process as a retrofit system at the municipal Wastewater Treatment Plant (WWTP) of Marpissa, Paros, Greece Petros Gikas (Greece)	(O-113) Innovative bioinspired intervention to control the growth of a new spit and reduce the occlusion of the mouth of the Goro lagoon (Italy) Corbau Corinne (Italy)
	17:15 - 17:30	(O-154) The water reuse potential of nature-based solutions in response to the increased water scarcity risks imposed by climate change Apostolaki Stella (Greece)	(O-080) Quantifying the effects of grazing beef cattle on microbial quality of surface water Gilboa Ben-David Yael (Israel)	(O-029) Modification of spent coffee grounds for their use as organic fertilizer Juglova Zuzana (Czech Republic)
	17:30 - 17:35	(F-031) Development of an NbS evaluation framework in the nexus of Sustainability, Circularity and Justice Mavrigiannaki Angeliki (Greece)	(F-041) Occurrence of ESKAPE pathogens in wash waters of the agri-food industry in view of the implementation of a closed loop economy Kanarek Piotr (Poland)	(F-010) Nature-based solutions using ecological engineering and dedicated to combine the mitigation of natural risks linked to water with benefits for biodiversity: considering interdisciplinary and transdisciplinary approaches Rey Freddy (France)
	17:35 - 17:40	(F-036) What do we know about the interactions between Nature-based solutions (NBS) and landscape? Sowińska-Świerkosz Barbara (Poland)	(F-053) Biological treatment of synthetic hypersaline wastewater: inoculum selection and start-up of a sequencing batch rector Polizzi Cecilia (Italy)	(F-014) Short term results of different planting technologies applied in the restoration of European habitats Carabassa Vicenç (Spain)
	17:40 - 17:45	(F-054) Integrating YamiTao traditional ecological knowledge into ecology education - an exemplification of Nature-Based Learning Lu Pei-Luen (Taiwan)	(F-002) Innovative hybrid dairy wastewater system assisted by an intelligent software tool for quality prediction of the processed product water to be used for crop irrigation in a greenhouse George P. Spyrou (Greece)	(F-042) Ecosystem services value dynamics under land use alterations in the upper Ganga riverine wetland Kansal Mitthan Lal (India)
	19:30 - ...	**Conference dinner @ Diogenis Restaurant**		
Wednesday 4 Oct		**IMPERIAL MAIN HALL**	**IMPERIAL ROOM 1**	**IMPERIAL ROOM 2**
	08:30 - 09:00	**Registration (lobby area)**		
		Session C1: Constructed wetlands technology I **Chair: Michail Fountoulakis & Seintos Taxiarchis**	**Session C2: Bio-based materials I** **Chair: Glenn Dale & Johannes Fabian Bauer**	**Session C3: Ecosystem services provision and assessment** **Chair: Oberholster Paul Johan & Sowińska-Świerkosz Barbara**
	09:00 - 09:15	(O-170) Performance of pilot-scale vertical flow constructed wetlands with and without aeration for municipal wastewater treatment Panagiotis Regouzas (Greece)	(O-003) Plant growth under different bio-composts applications Al-Busaidi Ahmed (Oman)	(O-081) Assessing and mapping yearly ecosystem services supplies in areas affected by land degradation processes with the support of remote sensing indices: two case studies from the NewLife4Drylands Project Ungaro Fabrizio (Italy)
	09:15 - 09:30	(O-117) Diffuse pollution treatment wetlands in cold climate: the importance of flood meadows Wahlroos Outi (Finland)	(O-064) Biomass waste-based material: Electrochemical performances and CO2 uptake capability Trinh Kieu Trang (Japan)	(O-046) Planting xerophytic shrubs significantly increased the carbon sequestration capacity and potential of sandy land Haotian Yang (China)
	09:30 - 09:45	(O-016) Effects of arbuscular mycorrhizal fungi on the metabolism of ibuprofen in constructed wetland with different substrates Chen Zhongbing (Czech Republic)	(O-129) Kitchen waste from cooked food: source of contamination or a valuable source for organic composting serving circular economy perspectives? Use of waste vermicompost as a soil amendment for greenhouse vegetables (II) Kinigopoulou Vasiliki (Greece)	(O-055) Life-cycle environmental assessment of strategies for sewage treatment and reuse: a case study considering local conditions in south-central Chile Neumann Patricio (Chile)
	09:45 - 10:00	(O-102) Long term performance of nature-based solutions as decentralized wastewater treatment: a case study of a retail store in southern Italy Marzo Alessia (Italy)	(O-167) Material flow analysis of the organic fraction of municipal solid waste in EU: monitoring current uses with emphasis on bio-based applications Stamatia Skoutida (Greece)	(O-034) The Ecological Engineering Nexus Accounting Framework: a tool for impact valuation of ecological engineering projects Schoeman Yolandi (South Africa)
	10:00 - 10:15	(O-166) Investigating GHG emissions from vertical subsurface flow (VSSF) Constructed Wetlands treating the UASB effluent originating from Seintos Taxiarchis (Greece)	(O-108) Organic-mineral composite material for removal of chromium from natural water Ekonomakou Antonia (Greece)	(O-137) Nature-based and solar energy building solutions in the water-energy-food nexus across diverse climatic zones in Europe Karamanis Dimitrios (Greece)
	10:15 - 10:20			(F-070) The Application of GeoPlanner in Local Development Management Jan Kazak (Poland)
	10:20 - 10:25	(O-186) Aerated wetlands for water reuse - Hydropolis Prague Rous Vit (Czech Republic)	(O-177) The awarded EUTeens4Green projects to TUC students: promoting nature-based solutions and circular economy Dionysis Tselentis (Greece)	(F-068) Assessment of carbon sequestration potential of targeted plants using remote sensing, GIS, and machine learning systems Aljabri Khalid (Oman)
	10:25 - 10:30			(F-007) Remote sensing-based water quality inversion in Třeboň fishponds: a comparative analysis of machine learning algorithms Ge Ying (Czech Republic)
	10:30 - 11:00	**Coffe break (lobby area) & Poster session**		
		Session C4: Constructed wetlands technology II **Chair: Fabio Masi & Chen Zhongbing**	**Session C5: Bio-based materials II** **Chair: Grant Clark & Panagiotis Regouzas**	**Session C6: Aquatic vegetation systems** **Chair: Vlysidis Anestis & Daniela Andrea López Leyton**
	11:00 - 11:15	(O-086) A natural coagulant for colour removal from raw and treated tequila vinasses (with constructed wetlands) Zurita Martínez Florentina (Mexico)	(O-012) Optimization of biochar filter for handwashing wastewater treatment and recycling at the point of use Bautista Quispe Jhonny Ismael (United Kingdom)	(O-026) A semi-self-sustaining microalgal-bacterial granular sludge process could reduce the cadmium-effect on wastewater treatment efficiency Li Yanyao (Belgium)
	11:15 - 11:30	(O-063) Treatment performance of constructed wetlands with subsurface horizontal flow after thirty years of operation Vymazal Jan (Czech Republic)	(O-047) Removal of Heavy Metals and Antibiotics from Water Using Biochar: From Lab to Real-World Use Ahmed Mushtaque (Oman)	(O-059) Assessing Contaminants of Emerging Concern, Heavy Metals, and Pathogens in Wastewater-Grown Microalgae for Agricultural Applications Uggetti Enrica (Spain)
	11:30 - 11:45	(O-180) Transforming polluted urban waters into liveable urban space with the help of NBS taking the Flussbad Berlin as an example Heribert Rustige (Germany)	(O-176) Production and characterization of Carbon Nanotubes and Graphene Oxide biochar nanocomposites from rice husks and sewage sludge and adsorption tests of six Emerging Contaminants from wastewater Panagiotis Regouzas (Greece)	(O-091) Algal technologies for green products – preliminary microbiological examination Istenič Darja (Slovenia)
	11:45 - 12:00	(O-079) Septage treatment using the First Stage of French Vertical Flow Constructed Wetlands: From the commissioning to the closure of the system	(O-161) Coffee-oil: production of biocrude oil from spent coffee grounds via hydrothermal liquefaction	(O-145) Tertiary wastewater treatment of anaerobic digestion effluents using a phytoremediation bioreactor

Time			
	Arévalo Durazno María Belén (Ecuador)	Vakalis Stergios (Greece)	Vlysidis Anestis (Greece)
12:00 - 12:05	(O-175) Large-scale constructed wetlands from Brazil to the Middle East: scaling up NBS Alexandros Stefanakis (Greece)	(F-030) Production and characterization of biochar produced from different type of bran Pořízka Jaromír (Czech Republic)	(F-055) Nitrogen fixation rate measurement by nitrogen fixing bacteria in a Lemna minor aquatic system Vlysidis Anestis (Greece)
12:05 - 12:10		(F-051) Activation of persulfate with hydrochar for catalytic degradation of bisphenol A in view of water treatment Zhang Xian (Belgium)	(F-069) Assessing Heavy Metal Pollution with Common Weeds: Unveiling their Bioindicator Potential Cakaj Arlinda (Poland)
12:10 - 12:15		(F-035) Acute toxicological evaluation of green biocides for outdoor cultural heritage, using Lactuca sativa seeds Rosa Manuel (Portugal)	(F-032) Study on algae composition of a river entering Taihu Lake and effect of constructed wetland Du Yingming (China)
12:15 - 14:00	**Lunch time!**		
PLENARY SESSION III Chair: Alexandros Stefanakis			
14:00 - 14:45	**Discussion panel The future of Ecological Engineering: integrating nature in problem-solving for a circular society**		
	Session C7: Sustainability in practice Chair: Alexandros Stefanakis	**Session C8: Water reuse and sustainability Chair: Jan Kazak & Marzo Alessia**	
14:45 - 15:00	(O-182) Sponsored speech: Novel equipment of wetlands maintenance Ruud Kampf (Netherlands)	(O-041) Utilizing treated wastewater for pasture irrigation: effects on productivity, plant community structure and soil properties Dovrat Guy (Israel)	
15:00 - 15:15		(O-092) Native vegetation for the reuse of treated municipal wastewater: Implications for greenhouse gas emissions Meister Alexandra (New Zealand)	
15:15 - 15:20	(F-071) The SunAir Fountain panel: solar-powered drinking water production from the air humidity Alexandros Stefanakis (Greece)	(F-047) Over 80% water recovery from urban greywater using nanofilter membranes – A Swedish case study Hall Ashley (Sweden)	
15:20 - 15:25		(F-027) Integrating academic knowledge on "Sustainability of Agricultural Water Management" Dahal Bishal (Finland)	
15:20 - 16:00	**Coffe break (lobby area)**		
PLENARY SESSION IV Chair: Alexandros Stefanakis & Andreas Schönborn			
16:00 - 16:45	**KEYNOTE**: Design of green infrastructure for a circular economy: case studies from different social and economic contexts Emmanouel Stefanakis (Sustainable Strategies International, USA)		
16:45 - 17:15	**CLOSING SESSION & AWARDS IEES2023**		

Thursday 5 Oct	**Tours & Fieldtrips**

LIST OF POSTER PRESENTATIONS

NAME	COUNTRY	POSTER TITLE
Pástor Michal	Slovakia	(P-002) Survival rate of selected newly planted urban trees in the city of Nitra (Slovakia) in the context of circular economy
Bauer Johannes Fabain	Germany	(P-005) Reclamation of land from fluid hydrocarbon extraction: State of the art and current challenges
Sirakov Ivaylo	Bulgaria	(P-006) Influence of different exposure times of treatment with a microelement in an aquaponic system on hydrochemical indicators and productivity of pepper (Capsicum annuum) cultivated integrated with common carp (Cyprinus carpio)
Zou Yuanchun	China	(P-008) Wetland-based solution for sustainable water management in a semiarid irrigation area subject to water use conflict
Aleksandryan Anahit	Republic of Armenia	(P-009) Tailings management facilities: risk reduction
Yang Mingyue	China	(P-010) Efficient removal and electrochemical detection of heavy metals by utilizing heavy-metal-tolerant bacteria from sludge
Lyu Xianguo	China	(P-011) Effect of reclamation on the vertical distribution of SOC and retention of DOC in the wetland landscapes in the Sanjiang Plain, Northeast China
Da Costa Maria	Portugal	(P-014) Physics of sound and SDGs: Raising awareness for the dangers of noise pollution
Çam Miyase Deniz	Türkiye	(P-015) Deep eutectic solvent pretreatment of olive tree biomass
Janczukowicz Wojciech	Poland	(P-016) The effect of external carbon source type and dose on nitrogen and phosphorus removal in Sequencing Biofilm Batch Reactor (SBBR)
Rodziewicz Joanna	Poland	(P-017) The influence of the method of organic substrate dosing on the efficiency of Sequencing Biofilm Batch Reactor (SBBR)
Jang Jeonghwan	Republic of Korea	(P-018) Aerobic DNRA-performing neobacillus sp. strain isolated from rice paddy field soil, Republic of Korea
Petkova Zdravka	Bulgaria	(P-019) Significance of soil type and applied fertilization on the content and uptake of macroelements with sunflower biomass in pot experiments
Barati Bahram	Belgium	(P-020) Enhancing biomass and phycocyanin productivity of spirulina sp. cultivated in anaerobically digested brewery effluent
Mielcarek Artur	Poland	(P-021) Biofilm - Supporting denitrification and dephosphatation with citric acid
Borodinecs Anatolijs	Latvia	(P-022) Dynamic electricity price: challenge for selection of cost-optimal PV Systems for households
Aljabri Khalid	Oman	(P-023) Remote sensing analysis for vegetation assessment of a large-scale constructed wetland treating produced water polluted with Oil hydrocarbons
Lin Chiao-Wen	Taiwan	(P-024) Greenhouse gas emissions from Lumnitzera racemosa mangroves
Lin Chiao-Wen	Taiwan	(P-025) Establishment of carbon sink coefficients of seagrasses in tropical islands
Isci Asli	Turkey	(P-026) Bioethanol production from microwave-assisted deep eutectic solvent pretreated wheat straw
Aslanhan Dicle Delal	Türkiye	(P-028) Deep eutectic solvent pretreatment of olive pomace
Kováts Nora	Hungary	(P-029) Can landraces better cope with environmental stress?
Schubert Hendrik	Germany	(P-030) Nature-based coastal protection measures in a circular society
Nabelek Jakub	Czech Republic	(P-031) Effect of wheat bran pre-treatment on isolation of ferulic acid
Steinbrecher Timo	Germany	(P-032) Production of biogenic aromatics from lignocellulosic agricultural residues
Sarabi Shahryar	Netherlands	(P-033) Promoting environmental justice in urban transitions: an embedded view
Lin Wei-Jen	Taiwan	(P-034) Mangrove carbon budgets suggest the estimation of net production and carbon burial by quantifying litterfall
Ghosh Sayanti	India	(P-035) Biochar supported Ag-TiO2: A green catalyst for degradation of pharmaceutically active compounds and disinfection in wastewater
Truu Jaak	Estonia	(P-036) Microbial fuel cells as a sustainable pathway to remediate oil-contaminated sediments and soils
Kimura Keiichi	Japan	(P-037) Cyanobacterial biocrust development on biomineralized sandy soil: new dryland restoration method
Tejada Manuel	Spain	(P-038) Green pepper (Capsicum annuum) fruit quality. Effects of the application of biostimulants obtained from slaughterhouse sludge
Tejada Manuel	Spain	(P-039) Application of a biostimulant obtained by enzymatic hydrolysis from slaughterhouse sludge in the bioremediation of soils polluted by the imazamox herbicide
Montero Pau	Spain	(P-041) Drone monitoring of extractive activities in Catalonia: a collaborative system for improving the sustainable management of the mining sector
Parrado Juan	Spain	(P-042) Design of a chemical/biological biphasic process for circular economy for the conversion of polyurethane into agronomic biostimulants
Kulbat Eliza	Poland	(P-043) Effect of sewage sludge mono- and co-digestion on nutrients removal from reject water
Parrado Rubio Juan	Spain	(P-044) Bioprocess of Keratin wastes conversion into agronomic biostimulants and biofertilizer
Wilinska-Lisowska Anna	Poland	(P-045) Possibilities of nutrients recovery from the liquid fraction of digestate from agricultural biogas plants in Poland
Montero Pau	Spain	(P-046) Remote sensing indicators for the study of drylands in Mediterranean climate
Ponis Stavros	Greece	(P-047) Be Well and Green When Digital - Lessons Learnt from the BeWEEN project
Truu Marika	Estonia	(P-048) Enhancing methane mitigation in landfills: insights from biocover composition and microbial parameters
Goulart Coelho Lineker Max	Denmark	(P-049) Proposal of a multicriteria decision making method to support the selection of nature-based solutions addressing rainwater management
Krzysztof Jóźwiakowski	Poland	(P-051) New generation Christmas tree shape hybrid treatment wetland for wastewater treatment in Roztocze National Park, Poland
Dong Pengyu	Belgium	(P-053) Optimized removal of silica during manure treatment by electrocoagulation-flotation (EC-F) in view of fouling prevention of reverse osmosis membranes
Gerasimova Iliyana	Bulgaria	(P-055) Fertilization and uptake of macroelements with maize biomass (a pot experiment with pelic vertisol)
Okuro Toshiya	Japan	(P-056) Effects of mixed seeding of several plants with different growth forms on mitigating sand drifting in desertified grassland in the Northeast Asia
Rusyn Iryna	Ukraine	(P-057) Green electricity: a renewable resources biotechnology and ecological engineering tool
Marijuan Raquel	Spain	(P-058) Evaluating the impact of Nature-based Solutions on the provision of water-related and water-dependant Ecosystem Services
López Leyton Daniela	Chile	(P-059) Hybrid constructed wetlands for enhance quality of urban aquatic ecosystems
Olaniran Ademola	South Africa	(P-060) Enhanced bioremediation of polycyclic aromatic hydrocarbons by laccases from two indigenous fungal isolates via the ABTS Mediator Systems
Wąs Adam	Poland	(P-061) Modelling policy options for GHG mitigation in Polish agriculture
Karamanis Dimitrios	Greece	(P-062) Climate-neutral EU Regions: Expanding the mission of 100 EU carbon-neutral cities to 30 European carbon-neutral regions through S3 platform until 2030
Perez Rubi Maria	Germany	(P-063) Scaling-up Nature-Based Solutions for decentralized greywater treatment retrofitted in urban areas of Costa Rica
Szymańska Magdalena	Poland	(P-064) A Bio-refinery concept for N and P recovery - a chance for biogas plant development
Sosulski Tomasz	Poland	(P-065) Reduced tillage, fertilizer placement, and soil afforestation as methods of CO2 soil emissions mitigation
Dafnos Ioannis	Greece	(P-067) Exploring the hydrological dynamics of Kifissos basin in Greece - an integrated analysis of water and groundwater resources
Gómez Silvia	Spain	(P-068) Agroecological solutions for resilient farming in West Africa: Identification of farmers' and communities' needs
Antonopoulou Georgia	Greece	(P-069) Biohydrogen production from household food waste through dark fermentation: the possibility of water minimization during dilution
Gómez Garrido Melisa	Spain	(P-070) Sustainable Environmental Management of pig production with an Integral Manure Management System with Constructed Wetlands
Rontogianni Anatoli	Greece	(P-071) High and low technological implementation of bio based energy sources in Europe: Comparisons and contrasts
El Bied Oumaima	Spain	(P-072) Decision Support System (DSS) for Controlled Pig Slurry Application and Sustainable Resource Management
Terrero Turbí Angélica	Spain	(P-073) Use of techniques to mitigate Greenhouse Gas emissions and ammonia from pig slurry storage
Dobele Aina	Latvia	(P-074) Aspects of urban agriculture in the sustainable development - the case of Latvia
Ho Chuan-Wen	Taiwan	(P-075) Enhancing carbon sinks through mangrove afforestation in a coastal constructed wetland park
Bauwe Andreas	Germany	(P-076) Performance of a denitrifying bioreactor for the treatment of nitrate-laden agricultural drainage water in northeastern Germany
Rubio-Clemente Ainhoa	Colombia	(P-077) Elimination of Crystal Violet in water by Pinus patula biochar: process optimization and validation
Rubio-Clemente Ainhoa	Colombia	(P-078) Life cycle assessment in the production of raw and Fe-modified biochars
Daphne Argyropoulou	Greece	(P-079) Greywater treatment with green walls for the washing of reusable cups and bottles
Fountoulakis Michail	Greece	(P-080) Integrate management of residues generated from olive cultivation and olive oil production process for soil resource recovery: the "Elaionas" project
Bąk Joanna	Poland	(P-081) Introduction of aquaponic farms partly supplied by rainwater into the urban tissue - possibilities, barriers, limitations and challenges
Seintos Taxiarchis	Greece	(P-083) BIODAPH2O – Investigating a novel system for tertiary wastewater purification
Klontza Eleftheria	Greece	(P-084) Arthrospira (Spirulina) platensis growth and biofixation of CO2 using cheese whey in the context of circular economy
Zabaniotou Anastasia	Greece	(P-085) Closed loops and the circular economy of polypropylene waste: Design, engineering and feasibility of pyrolysis
Tong Shouzheng	China	(P-086) The driving mechanisms for community expansion in a restored Carex tussock wetland
Zhang Mingye	China	(P-087) Effects of melatonin priming on Suaeda corniculata seed germination, antioxidant defense, and reserve mobilization: Implications for salinized wetland restoration
Lin Wei-Jen	Taiwan	(P-088) The carbon budget in aquaculture systems with the Asian clam (Corbicula fluminea) in eastern Taiwan
K. Lasaridi	Greece	(P-089) Comparative analysis of composting source-separated biowaste and the organic fraction of the Chania MBT plant
Maria Frantzeskou	Greece	(P-090) Short term effects of non-tillage on soil health restoration in Mediterranean environments
Athanasios Tsilimigkras	Greece	(P-091) Drivers of Change: Analyzing the Historical Shifts and Future Pathways for Biophysical and Socioeconomic Influences on Land Degradation in the Mediterranean

Session A1: Circularity in the built environment

A spatial perspective on circular economy and the construction sector within Flanders (Belgium).

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Keywords: construction sector, circular economy, Flanders, spatial perspective

ABSTRACT

The Manifesto of the International Ecological Engineering Society addresses, amongst other things, the unsustainable use of resources that may have disastrous and irreversible impacts at local and global scale and introduces the concept of systems thinking as a critical step towards the development of new holistic and interdisciplinary engineering solutions at all scales. By re-establishing cycles of materials in circular systems we can deal with resource scarcity (IEES, 2022). In this paper we aim to elaborate further on this topic within the regional context of Flanders, within the domain of spatial and regional planning and focussing on the transition towards a more sustainable and circular built environment.

The circular transition is not only changing our economy, but also our space. This makes the transition to a circular economy - besides a socio-economic task - also an issue of spatial planning and governance. From the focus of spatial and regional planning, we need to free up space and at the same time transform space so that circular activities can emerge, grow and become mainstream.
In the end we want to answer these main research questions with our research:

- *What is the impact of circular economy on the construction sector in Flanders?*
- *Which (size of) plots do we need to make the construction sector more circular?*
- *What flows are created by this circularity and how can we organize them?*

In this paper we aim to describe the current organisation of the construction sector within Europe and Flanders and their societal and environmental impact, and the challenges we are facing to make the current practice more circular. In the end we would like to propose some future changes. We use mixed methods to answer the research questions: literature study, GIS and conceptual design.

The construction sector is responsible for 38% of global CO_2 emissions and for about half of all extracted materials and roughly one-third of water consumption in the European Union (United Nations Environment Programme, 2020). Within Flanders we have similar figures. Expenditures related to residential housing are linked to just over a quarter of the overall Flemish carbon footprint (Breemersch, Lam Wai, Vercalsteren, 2020). The European Commission has pronounced in the Green Deal to become the first climate-neutral continent and adopted a set of proposals to reduce the net greenhouse gas emissions by at least 55%. Europe has set ambitious targets to reduce emissions related to buildings by 48% by 2030 while the planned reduction of carbon emissions from residential buildings is 50% by 2030. The European Commission also proposed to set a benchmark of 49% of renewables used in buildings by 2030 (European Commission, 2021). The Flemish Energy and Climate Plan (Vlaams Energie en Klimaatplan, VEKP) was recently approved in 2023 (Flemish Government, 2023) . This plan strengthens efforts in the transport, buildings, agriculture, (light) industry and waste sectors, the so-called ESA sectors. The ambition in the new 2021-2030 VEKP in terms of GHG emission reductions in the ESA sectors is increased to -40% by 2030 (compared to 2005), but is still less ambitious than the European targets.

To achieve these targets we need to rethink the construction sector and system. First of all circular building or constructing refers to multiple levels ranging from (building) materials, building elements and buildings to infrastructure works and regional development. Circular building also refers to all phases of the building cycle and to all the phases of circularity. From the (avoidance of) extraction of raw materials, to the design and construction of a structure, and to the reuse and recycle of (parts of) structures and reclaimed materials. In the figure below just one of the possible relations within a circular construction system is indicated, the reuse

of materials. Buildings can be dismantled and elements and materials can be separated to direct reuse in new buildings or renovation projects. In addition (raw) materials can also be recycled and transformed into new building materials rather than end up on the waste piles.

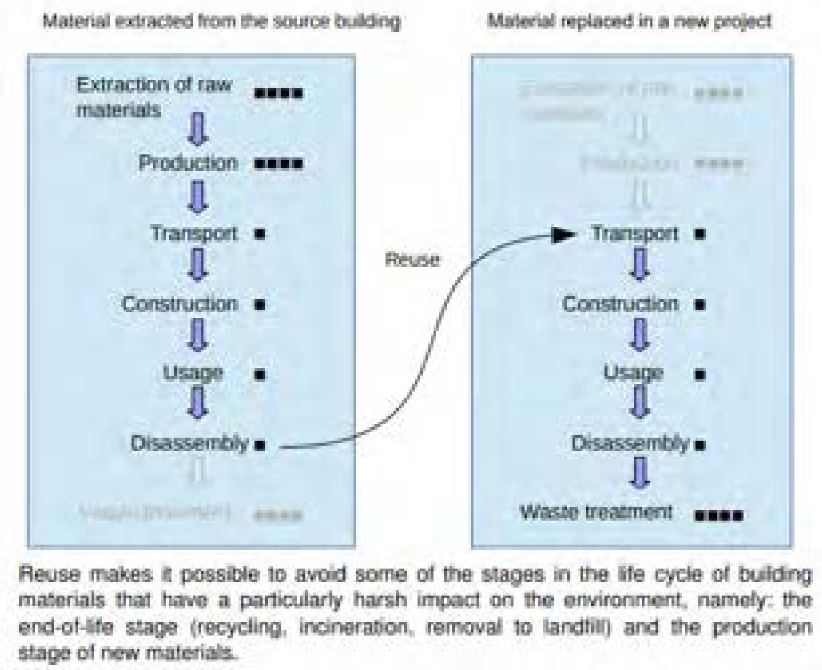

Figure 1: The advantage of reuse. (Rotor asbl & Brussels-Capital Region, 2015)

By 2035, Flanders will have, by estimation, over 300,000 inhabitants more than today. These demographic changes and their sociological impact will further increase the demand for buildings and adapted infrastructure. By 2035, Flanders is calculated to need more than 295,000 new housing units. This is a growth of 10.5% (Verachtert, Poelmans & Vanderstraeten, 2022). The existing houses, over half of which were built prior to 1970, are characterised by their relatively large size and low energy scores. Breemersch, Lam Wai and Vercalsteren (2020) calculated the impact of the renovation of the current building stock, using two circular strategies. The first strategy aims to make more intensive use of the living space in houses by reducing the size of new dwellings and through the splitting up a small fraction of existing larger detached houses into semi-detached houses. The second circular scenario looks at the impact of using a different construction method and the increase of recycling and reuse of demolished materials. In the paper we will elaborate on the results in relation to the expected use, reuse and reduction of specific building materials and the associated locations needed to extract, produce and (re-)assembly these building materials in a more circular construction system within Flanders. For these activities, available space is important but just as important is the distance to the housing and construction market. Flanders is characterized by a sprawled pattern of housing, which increases the challenges of logistics and transport of the circular materials for the building sector and thus hinders the opportunities for urban mining (Pisman, A. & Vanacker, S., 2021)

But of course we do not only need to consider the construction materials but also the treatment of construction and demolition waste, such as rubble, wood waste, insulation, broken glass and rebar created during the construction, (re)building and demolition of buildings, roads, pavements etc. Construction and demolition waste is by far the largest waste stream in Flanders (in 2018 22% of primary industrial waste, five times more produced than household waste). However, more than 90% of construction and demolition waste is recycled (Pisman *et al*., 2021). The stony fraction (which is also the largest fraction) is processed into recycled aggregates. This is done by mechanical treatments such as sorting, crushing and screening and can take place at a fixed site at a "fixed rubble crusher" or at a job site, with a mobile plant. In the latter case, debris from a particular construction or demolition site is processed on site and no debris may be brought in from other locations. In 2018, 84% of recycled aggregates came from a fixed debris crusher compared to 12% from mobile installations. Quantities have increased from about 0.5 million tons in 1997 to 16 million tons in 2018 (Department of Environment and Spatial Development, OVAM, VITO, 2021).

The analysis of specific building materials, according plots and flows for the construction and reconstruction of these materials will lead to specific conclusions for the Flemish situation and to general conclusion within a European context. These conclusions will deal with still necessary (and more local?) plots for the extraction of raw materials, many more plots for demolition and stockade of used building materials that can be organised on a local and a regional scale, the impact of the flows that will be created by these (re)used building materials and the need for more research about urban mining and potentially reusable constructions.

References:

Breemersch, Lam Wai & Vercalsteren, 2020, Impact of Circular Economy on Achieving the Climate Targets: Case Housing. https://circulareconomy.europa.eu/platform/sites/default/files/impact_of_circular_economy_on_achieving_the_climate_targets_-_case_housing.pdf

Departement of Environment and Spatial Development, OVAM, VITO, 2021. Monitoringsysteem Duurzaam Oppervlaktedelfstoffenbeleid (MDO). https://omgeving.vlaanderen.be/monitoringsysteem-duurzaam-oppervlaktedelfstoffenbeleid-mdo

European Commission, 2021. 'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en#renovating-buildings-for-greener-lifestyles

Flemish Government, 2023, Ontwerp Vlaams Energie- en Klimaatplan 2021-2030. https://www.vlaanderen.be/veka/energie-en-klimaatbeleid/vlaams-energie-en-klimaatplan-vekp-2021-2030

International Ecological Engineering Society (IEES), 2022. Our Manifesto. https://iees.ch/our-manifesto/

Pisman, A., Vanacker, S., Bieseman, H., Vanongeval, L., Van Steertegem, M., Poelmans, L., Van Dyck, K. (Eds), 2021. Ruimterapport 2021. Brussel: Departement of Environment and Spatial Development https://omgeving.vlaanderen.be/het-ruimterapport

Pisman, A. & Vanacker, S., 2021. Diagnosis of the state of the territory in Flanders : reporting about new maps and indicators differentiating between urban and rural areas within Flanders. Smart and sustainable planning for cities and regions : results of SSPCR 2019. In Green Energy and Technology p.209-224 https://link.springer.com/chapter/10.1007/978-3-030-57764-3_14

Rotor asbl & Brussels-Capital Region, 2015, How can reusable materials be extracted from public buildings? Handbook for reuse off site

United Nations Environment Programme, 2020. Emissions Gap Report 2020. Nairobi. https://www.unep.org/emissions-gap-report-2020

Verachtert, Poelmans & Vanderstraeten, 2022. Waar woont de Vlaming in 2035. https://researchportal.be/nl/publicatie/waar-woont-de-vlaming-2035

Valorisation of the stabilized organic fraction of mixed municipal waste as building materials within a circular economy

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Keywords: waste recovery; hydrothermal carbonization; hydrochar; sustainable particleboard; blended mortar

ABSTRACT

The urgent minimization of CO_2 emissions from the construction sector is driving the use of urban, agroforestry and industrial wastes as substitutes for raw materials. This approach not only mitigates the intensive exploitation of primary resources, but also offers a solution to dispose of the massive waste streams generated worldwide.

Biomass residues display a very promising potential in the building materials industry, but a number of drawbacks, mainly due to their high moisture content, low mechanical properties and poor compatibility with other components, still limit their direct application.

Biochar, the solid product from the thermochemical transformation of biomass, is receiving great interest as a carbon-negative material with efficient performance in particleboards, mortars, concrete, etc. The production of biochar involves heat treatment of the precursor in an oxygen-free atmosphere at temperatures typically ranging from 300 °C to 650 °C. This technology is severely penalized by the high moisture content of most bio-waste

As a competitive alternative, hydrothermal carbonization (HTC) is an affordable technology particularly suitable for thermochemical processing of wet feedstocks, as water is involved as a reactant. Hydrothermal degradation of biomass follows similar reaction mechanisms as standard carbonization (hydrolysis, dehydration, decarboxylation, aromatisation and recondensation), but takes place at milder temperatures of 180-250 °C under the respective water vapor saturation pressure. Under such conditions, the high ion concentration resulting from the reduced dielectric constant of subcritical water favours the decomposition of biopolymers and the solubilization of organic compounds. Studies have shown that HTC successfully converts a wide variety of biomass residues into a carbon-enriched solid (hydrochar) and an aqueous phase that can be recirculated to the process or used as a source of valuable organic compounds. In addition, the gas release is typically less than 10 wt%.

The transformation of organic waste into hydrochars is dictated by feedstock composition and operating conditions, and therefore a wide variety of materials can be obtained for various applications such as energy production and storage, soil improvement, adsorbents, catalysis, chemical and nutrient recovery.

This study explores the use of hydrochar as a challenging option for the development of novel low-CO_2 building materials. Specifically, it is approached for sustainable particleboards and mortars.

Mechanical and biological treatment (MBT) is a globally widespread technology that aims to recover materials and reduce the discharge of mixed municipal waste. Currently, stabilized organic waste (SOW) from MBT remains a problematic stream, as it is not counted as EC compost and is traditionally used for landfill cover purposes, or directly landfilled.

In this study, stabilized organic waste with a moisture of 48.9 wt% and inorganic fraction of 35.5 wt% is selected as feedstock (Figure 1). The HTC process consisted of the treatment of SOW with water (solid-to-water ratio of 1:4 by weight) at temperatures of 180 and 200 °C and the respective pressures of 9 and 16 bar for 2 hours (3-L stainless-steel lined pressure reactor ILSHIN).

It is found that, without pre-drying, SOW is efficiently transformed into 76.5 and 71.8 wt.% of hydrochars HSOW-180 and HSOW-200, with a recovery (Crec) of 77 and 68 wt.% of carbon from the initial residue (dry basis), respectively. Both materials are pathogen-free and stable, with no degradation observed over time.

Figure 1. Transformation of stabilized organic fraction from MBT by means of hydrothermal carbonization and application of hydrochars as construction materials.

The modification of the chemical composition of SOW (Table 1) conforms to the general profile described for biomass conversion by HTC, although the magnitude of the changes is significantly smaller since the feedstock had already been subjected to biological pre-treatment. It is worth noting the high ash content of SOW-based hydrochars, which hinders their use in bioenergy, advanced carbon materials, etc., but makes them interesting to apply in construction.

Table 1. Chemical features of the original waste (SOW-MBT) and the hydrochars produced at 180 and 200 °C for 2 hours (referred to dry basis)

Material	Yield (wt%)	Crec (wt%)	Ash (wt%)	Volatile Matter	Fixed Carbon	C (wt%)	H (wt%)	O (wt%)	Atomic ratio O/C	Atomic ratio H/C
SOW	-		35.5	59.1	5.4	34.9	4.2	23.0	0.49	1.44
HSOW-180	76.5	77	35.9	57.4	6.7	35.3	4.5	22.8	0.48	1.43
HSOW-200	71.8	68	42.8	48.9	8.3	32.9	3.8	19.0	0.43	1.39

The presence of extractives as natural binders facilitates the successful agglomeration of HSOW-180 particles at 25 °C by pressing at 300 MPa without dwell time (static hydraulic press). Circular probes of 12.5 mm in diameter and up to 10 mm in height and rectangular-shaped elements of 50.5 × 10.4 × 5-6 mm were prepared. Heating of the probes in an inert atmosphere (N_2) at temperatures below 300 °C for periods of less than 2.5 hours yielded binder-free items with a density of 1118 kg/m^3.

12.5 mm in diameter and up to 10 mm in height and rectangular-shaped elements of 50.5 × 10.4 × 5-6 mm were prepared. Heating of the probes in an inert atmosphere (N_2) at temperatures below 300 °C for

The affinity to water, which is one of the main weaknesses of biomass-based particleboards and is also observed in those containing hydrochars, is notably reduced with post-curing. The HSOW-180 probes absorb only 5.2 wt% after immersion in water for 2 hours and experience a thickness swelling limited to 1.5%, which implies an excellent dimensional stability.

The compression strength of 35.09 MPa, the modulus of elasticity of 540 MPa and the modulus of rupture of 18.53 MPa of the HSOW-180 items compete favourably with the values shown by probes produced from lingo-cellulosic materials and exceed those achieved with agricultural residues. Such characteristics indicate great prospects for SOW-derived hydrochar as a resource for filler boards in duct-housing structures as well as in non-structural panels and partitions.

On the other hand, the high amount of inorganic matter (Table 1), with ~ 16 wt% silica, in the hydrochar produced at 200 °C suggests the potential of HSOW-200 as a substitute for reducing cement consumption in mortars. For a comprehensive evaluation of its impact on the performance of both fresh and hardened mortars, the cement was partially replaced with 1.25, 2.5 and 5 wt% of hydrochar. The respective blended mortars correspond to HSOW-200-1.25, HSOW-200-2.5 and HSOW-200-5.

It is observed that the presence of hydrochar does not significantly modify the water need for mortar production, and with 2.5 and 5 wt% cement substitution, the water requirement is only 1 and 3 wt% higher.

The addition of 1.25% HSOW-200 results in a slightly higher consistency (Table 2), which may be due to a better combination with water as a consequence of the presence of some hydrochar particles larger than those of cement. For higher dosage, this effect appears compensated by the high water absorption capacity of HSOW-200 and the incorporation of 5 wt% reduces the workability of the blended mortar HSOW-200-5. The setting time is significantly affected when 5 wt% cement is replaced by hydrochar, being both the onset and end of setting delayed.

Table 2. Characteristics of fresh and hardened mortars

	Fresh mortar		Hardened mortar (28-days)			
Sample	Consistency (mm)	Bulk density (g/cm^3)	Bulk density (g/cm^3)	Compression strength (MPa)	Thermal conductivity (W/m. K)	Electrical resistivity (kΩ.cm)
Control	119	2.22	2.16	60.48	1.66	6.12
HSOW-200-1.25	128	1.97	1.89	31.52	1.34	5.13
HSOW-200-2.5	119	1.85	1.90	23.88	1.26	4.52
HSOW-200-5	109	1.80	1.90	26.65	1.40	4.22

Partial replacement of cement by hydrochar induces a decrease in the bulk density of the mortar in fresh and hardened states and leads to a significant reduction in the compression strength of mortars and, to a lesser extent, in the flexural strength. However, compression strength of 23.88-31.52 MPa of the blended mortars holds promise for use in plastering, rendering, masonry and partition blocks. Moreover, the presence of hydrochar decreases the thermal conductivity and electrical resistivity of the mortar by 25-30%, which favors thermal insulation properties and durability.

In conclusion, the alternative presented in this paper fits into a circular economy framework based on the recovery of low-quality biomass waste through mild hydrothermal carbonization to provide secondary raw materials for sustainable construction.

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References:

Bernat, K., Wojnowska-baryła, I., Zaborowska, M., Samul, I. 2021. Insight into the composition of the stabilized residual from a full-scale mechanical-biological treatment (MBT) plant in terms of the potential recycling and recovery of its contaminants. Sustainability. 13 1–16. https://doi:10.3390/su13105432.

Funke, A., Ziegler, F., 2010. Hydrothermal carbonization of biomass: A summary and discussion of chemical mechanisms for process engineering. Biofuels, Bioprod. Bioref. 4, 160–177. https://doi:10.1002/bbb.198.

Zhuang, X., Liu, J., Zhang, Q., Wang, C., Zhan, H., Ma, L. 2022. A review on the utilization of industrial biowaste via hydrothermal carbonization. Renewable and Sustainable Energy Reviews. 154, 111877. https://doi:10.1016/j.rser.2021.111877.

Madurwar, M.V., Ralegaonkar, R.V., Mandavgane, S.A., 2013. Application of agro-waste for sustainable construction materials: A review. Construction and Building Materials. 38, 872–878, http://dx.doi.org/10.1016/j.conbuildmat.2012.09.011

Maljaee, H., Madadi, R., Paiva,H., Tarelho, L., Ferreira, V.M., 2021. Incorporation of biochar in cementitious materials: a roadmap of biochar selection. Construction and Building Materials. 283 122757, https://doi.org/10.1016/j.conbuildmat.2021.122757.

Maljaee, H., Paiva, H., Madadi, R., Tarelho, L.A.C., Morais, M., Ferreira, V.M., 2021. Effect of cement partial substitution by waste-based biochar in mortars properties., Construction and Building Materials. 301, 124074. https://doi:10.1016/j.conbuildmat.2021.124074.

Santos, M.M., Diez, M.A., Suárez, M., Centeno, T.A., 2021. Innovative particleboard material from the organic fraction of municipal solid waste. Journal of Building Engineering. 44, 103375. https://doi:10.1016/j.jobe.2021.103375.

Formalising the temporal aspect of timber component reusability in a circular construction indicator

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Keywords: Timber reuse; Circular construction; Waste minimisation

EXTENDED ABSTRACT

1 Introduction

To make a shift toward a Circular Economy (CE), it is vital to enable the measurement of circularity and, thus, the progress toward a CE that is made [1]. Therefore, Anastasiades et al. (2023a) presented their Circular Construction Indicator (CCI) that considers the 4 Rs of the CE in the Design, Construction and End-of-Life (EoL) phase. They point out that the number of components that can be reused, recycled and collected for energy recovery in the EoL phase is time-dependent, corresponding to the construction's age and condition. Therefore, they propose to implement service life prediction models to estimate the amount of materials that can be assigned to each value stream [2]. This is particularly important for timber components, considering the increasing attention for wood construction. The more so, because the required tree growth periods before harvesting vary from 30 to 100 years [3] so when all demolition wood is merely incinerated after a first use cycle, the timber rotation period will rarely be matched . This will sooner than later lead to an unsustainable timber construction industry [4]. Therefore, Anastasiades et al. (2023b) presented a reuse potential indicator for timber components based on a service life prediction model. The indicator predicts the decay rate for a certain timber component in a certain environment and composition with other components. Subsequently, it determines the reusability rating according to the European standard EN 252 [5] and shows how the rating progresses in time [6]. Combining the knowledge of material decay with circularity principles, such as disassemblability, allows designers to more accurately and more efficiently improve the circularity of their designs.

In this paper, a methodology is presented to combine the timber reuse potential indicator with the CCI.

2 Material and methods

In a construction's EoL phase, the number of components that can be collected for reuse, recycling and energy recovery can be described as interdependent through a time-quality function that is determined by factors describing design specifications, environmental aspects and material properties [2]. When considering the timber reuse potential indicator [6], this time-quality function is embodied by the decay rate U_{wood}. This is the speed, expressed in mm/year, at which fungal decay progresses along the thickness of the considered timber component. For above-ground exposure, $U_{wood,a\text{-}g}$ is given in Eq. (1) [6].

$$U_{wood,a-g} = k_{wood} \cdot k_{climate} \cdot k_{paint} \cdot k_{width} \cdot k_{thickness} \cdot k_{connection} \cdot k_{contact} \cdot k_{position} \left[\frac{mm}{year}\right] \quad (1)$$

With:

- k_{wood}: a parameter corresponding to the above-ground durability of the used wood species
- $k_{climate}$: a parameter considering the region where the wood is exposed
- k_{paint}: a parameter that considers a paint layer
- k_{width}, $k_{thickness}$: geometric parameters
- $k_{connection}$: a parameter considering the type of connection to other components
- $k_{contact}$: a parameter considering the type of contact to other components
- $k_{position}$: a component considering the position of the component in the greater structure

This decay rate combined with the corresponding EN 252 based reuse potential rating (see [6]), can be used to objectively determine the fractions of material that are collected for resp. recycling ($C_{R,d}$), reuse ($C_{U,d}$), and energy recovery ($C_{E,d}$). The procedure will be determined and tested using the case of a timber Warren truss bridge structure and a wooden bridge deck, located in Flanders, Belgium. For the Warren truss, the components will be considered as Norway spruce (*Picea abies*) of strength class C24, according to the EN 338 [7], with a thermal modification for above-ground outdoor use. The bridge decking will be considered as Southern yellow pine (*Pinus spp.*) with an acetylation treatment.

3 Results

Considering the case study of the timber Warren truss bridge structure and the bridge decking, a total of 10 timber reuse potential simulations are necessary: there are 4 beam sizes and the bridge deck plank, and for each the decay is assessed at the connection and along the free length of the component. As an example, the simulation for the bridge deck plank is shown in Figure 1.

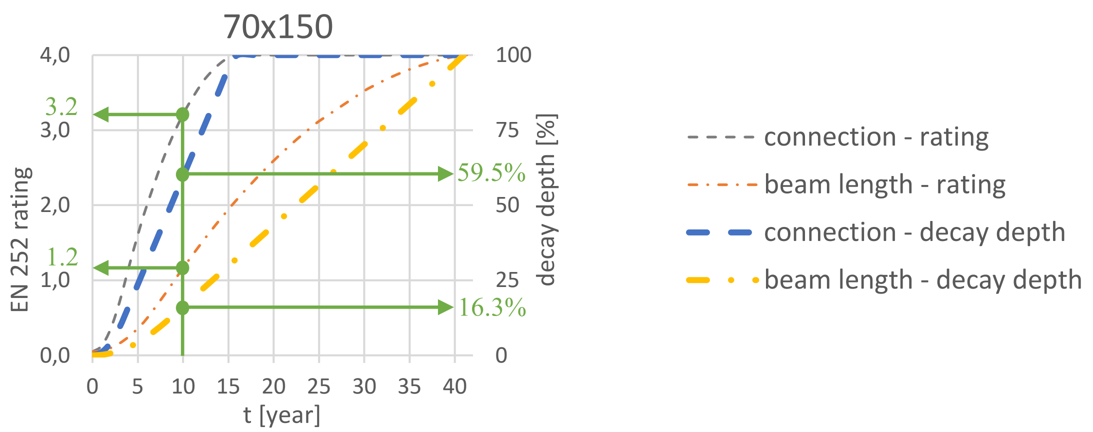

Figure 1: decay rating and decay depth for the bridge deck plank

Combining the resp. curves for the decay rating and decay depth, allows to determine the different EoL streams, which are variable in time. In the example of the bridge decking, the decay depth along the plank's length is 16.3% after 10 years with a corresponding reuse rating of 1.2 . The reuse rating prescribes in this case that the decayed 16.3% should be collected for energy recovery. The remaining 83.7% can be collected for reuse. At the connection, the decay depth is 59.5% after 10 years, with a corresponding reuse rating of 3.2 . In this case the decayed 59.5% is again collected for energy recovery, but the remaining 40.5% should be collected for recycling.

The decay around the connection and along the beam's length clearly progress at different rates, which needs to be considered to determine the different EoL streams as well. Therefore, the simplified assumption is made that 15% of the beams' lengths is assigned to the connection. In this way, a weighted average can be calculated for the different EoL fractions for each beam type, as shown in Eq. (2) for the reuse stream $C_{U,d,i}$ of beam type *i*. The equation is equivalent for the recycle stream $C_{R,d,i}$.

$$C_{U,d,i} = 0.15 \cdot C_{U,d,i,connection} + 0.85 \cdot C_{U,d,i,free\ length} \qquad (2)$$

With:

- $C_{U,d,i}$: the reuse fraction of beam *i* in the EoL phase
- $C_{U,d,i,connection}$: the reuse fraction at the connection of beam *i*
- $C_{U,d,i,free\ length}$: the reuse fraction along the free length of beam *i*

These different EoL fractions for each beam type can be combined into weighted overall EoL fractions using the beam types' weight fractions in the total structure. As an example, this is shown for the reuse stream $C_{U,d}$ in Eq. (3).

$$C_{U,d} = \sum_{i=1}^{k} \frac{M_i}{M_d} \cdot C_{U,d,i} \tag{3}$$

With:

- $C_{U,d}$: the total reuse fraction of the construction
- $C_{U,d,i}$: the reuse fraction of beam type i in the EoL phase
- M_i: the combined mass of all beams of type i
- M_d: the total mass of the structure

Considering that Norway spruce has an average density of 405 kg/m³ and Southern yellow pine 420 kg/m³, the total EoL fractions can be determined in time, using the methodology described above. For the presented case study, the different fractions $C_{U,d}$, $C_{R,d}$ and $C_{E,d}$, as well as the total waste W_d are plotted in time in Figure 2.

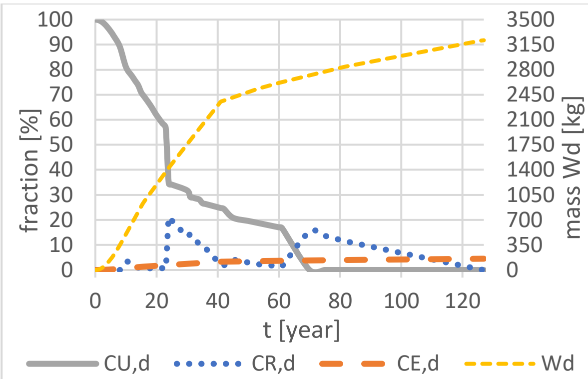

Figure 2: evolution in time of the EoL fractions

4 Discussion

The results in Figure 2 indicate that after 15 years of service, 71% of the bridge's timber components can still be reused. In addition, when considering the decay rates and reuse ratings (of which an example is shown in Figure 1), it becomes clear that both the connections and the timber size, or more generally the shape of the beam section, have a large influence on the reusability. Initially, the simplified assumption was made that 15% of the beams' lengths is assigned to the connection. Considering Eq. (2), it becomes clear that a smaller or larger connection influences the reuse stream $C_{u,d}$. Also the type of connection (e.g. bolted or clamped) will have an influence. Therefore, a sensitivity analysis is performed of which an example is shown in Figure 3. Now the reusable portion of timber components after 15 years varies between 65%, in the case where the connections encompass 30% of the beams' lengths, and 77%, in the case where the connections are clamped instead of bolted. It is self-evident that many more combinations are possible. Hence, the service life design of a timber structure is highly influenced by the design of the connections.

A similar sensitivity analysis is performed for different cross sections of the beams, showing that choosing the cross sections wisely is equally important in order to optimise the reuse stream.

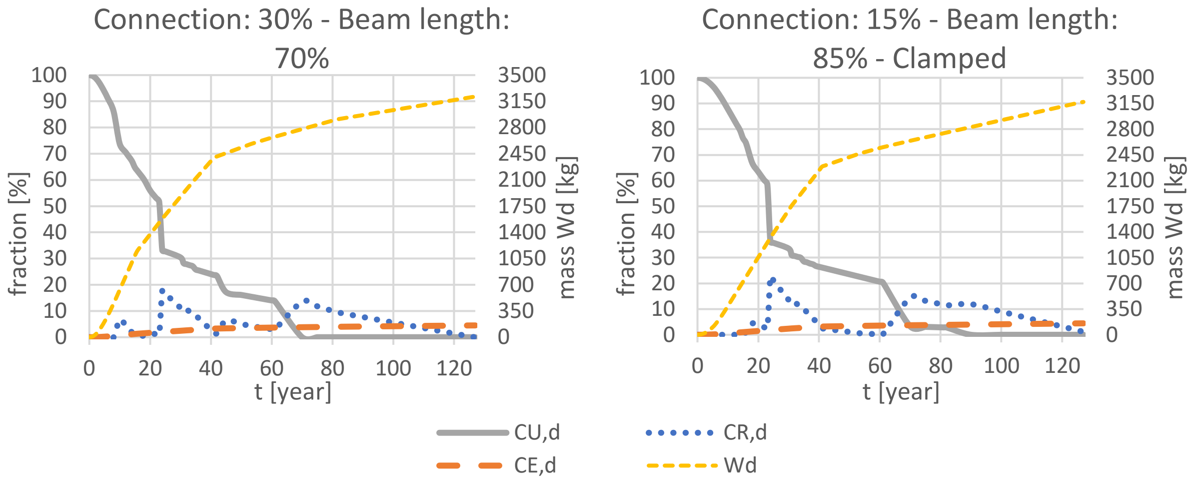

Figure 3: influence of the connection size and type on the reuse stream

5 Conclusion

This paper presents a methodology to integrate a timber service life prediction model with a circular construction indicator to formalise the temporal aspect of timber component reusability. The methodology shows the time-dependency of the material fractions destined for reuse, recycling and energy recovery. In addition, it points out where designers can optimise their design further for component reusability. The test case in this investigation already points out that the design of the connections and the choice of the cross sections greatly influence the timber components' durability and, consequently, their reusability in time. Future research could therefore focus on the design of timber connections and how these can be optimised for reuse.

The major contribution of this research is that it raises designers' awareness of the reuse potential of timber components and how to improve it. This awareness should prevent reusable timber from being sent straight to heat and power plants for energy recovery. After all, ideally, components remain in their highest possible value stream. Hence, it allows the construction industry to progress towards a truly circular construction industry.

References:

[1] International Organisation for Standardisation, Sustainability in Buildings and Civil Engineering Works - Design for disassembly and adaptability - Principles, Requirements and Guidance, Geneva, 2020.

[2] K. Anastasiades, J. Blom, A. Audenaert, Circular Construction Indicator: Assessing Circularity in the Design, Construction, and End-of-Life Phase, Recycling. 8 (2023). https://doi.org/https://doi.org/10.3390/recycling8020029.

[3] M.H. Ramage, H. Burridge, M. Busse-Wicher, G. Fereday, T. Reynolds, D.U. Shah, G. Wu, L. Yu, P. Fleming, D. Densley-Tingley, J. Allwood, P. Dupree, P.F. Linden, O. Scherman, The Wood from the Trees: The Use of Timber in Construction, Renew. Sustain. Energy Rev. 68 (2017) 333–359.

[4] K. Anastasiades, J. Blom, M. Buyle, A. Audenaert, Translating the circular economy to bridge construction: Lessons learnt from a critical literature review, Renew. Sustain. Energy Rev. 117 (2020). https://doi.org/https://doi.org/10.1016/j.rser.2019.109522.

[5] CEN, Field test method for determining the relative protective effectiveness of a wood preservative in ground contact, Brussels, 2014.

[6] K. Anastasiades, H. Bielen, G. Cantré, C. Brischke, P.B. Niekerk, A. Audenaert, J. Blom, In-ground and above-ground service life prediction for timber reusability - Progressing towards circular construction, TBD. (2023).

[7] CEN, Structural timber - Strength classes, Brussels, 2016.

Waste to construction: A novel Hempcrete product research

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Keywords: construction, energy conservation, hemp, LCA, monitoring vs simulation, unfired binders

ABSTRACT

World population is growing and so are cities. Projections of current trends estimate that urbanites will comprise 68% of world population by 2050 (UN, 2017). Both processes – population growth and urbanization – create a growing need for rapid construction of all building types. However, the construction industry is already responsible globally for significant portions of energy consumption, CO_2 emissions and waste products. As such, it is directly responsible for resources usage, environmental degradation, and public health. The way we build, not least the materials we use, impact energy consumption it two ways. The extraction of raw materials, their processing into construction materials and components, transporting these, the construction process itself, and finally building demolition, account for at least 10% of the overall energy used in industrialized countries, a percentage known as Embodied Energy (EE). Another 40% account for the energy used primarily for heating and cooling buildings, as well as lighting and ventilating them, and providing for other energy-related needs (pumps, elevators, etc.) and are known as Operational Energy (OE). However, as building design and construction become more energy-aware and environment-responsive, the relative parts of EE and OE change constantly - insulating materials allow energy conservation, thus a lower OE account, but need much more EE in their production compared to conventional, energy wasting construction (Lützkendorf et al., 2014).

Thus, a wholistic approach is needed if the construction industry is to limit its environmental impact in all respects and its products are to provide decent indoor conditions at a minimal energy investment.

This research attempts to tackle the issue wholistically:

1 using waste products for the production of construction materials;
2 which have a low EE and high carbon sequestration, or low embodied carbon (EC);
3 and promote the construction of building envelopes with a high insulating value, lowering OE.

Cement and concrete are currently the most ubiquitous building materials worldwide, with global cement-based concrete production surpassing 10 billion tons per year. Cement has a high EE since its production involves a kiln temperature of 1450°C, this in addition to the energy involved in quarrying, crushing and other stages of pulverizing rock. Although concrete has significant advantages as a structural material, its thermal properties are poor and thus it is a poor wall infill material, though it is used as such as well. Alternative infill materials, such as Autoclaved Aerated Concrete (AAC) blocks, have a thermal conductivity lower than that of the concrete and its derivatives, e.g., Hollow Concrete Blocks (HCB). As such, they allow the production of buildings with a lower OE, yet still have a high EE and EC due to their energy intensive production processes (involving high temperature and vapor pressure autoclave) and ingredients, not least lime and alumina powder. Nevertheless, AAC has become very popular and is extensively used for a number of reasons.

As of recent, low EE and EC products have been introduced as AAC substitutes, among them Lime Hemp Concrete (LHC) otherwise known as Hempcrete. This has been a significant step forward since hemp shives used in the production of LHC are a waste product of the hemp agro-industry focusing on the plant's fibres, accounting only for 30% of the plant. Hemp shives are very lightweight with a high air content which gives them insulating properties. However, the other component of LHC, lime, is still an energy intensive material, with EE and EC values very similar to those of cement (~5 MJ/kg EE and ~0.8 kg CO2/kg EC respectively) (Hamond & Jones, 2008). Potential substitutes for lime include clay which is abundant worldwide and can be used as an unfired binder.

The **first stage** of this research program focused on the analysis of different waste byproducts originating from quarrying activities, e.g., clay, limestone, dolomite, basalt. Chemical and phase compositions of the alternative

binders were determined by X-Ray Fluorescence (XRF), X-Ray Diffraction (XRD), Scanning Electron Microscopy (SEM) with Energy Dispersive Spectroscopy (EDS). Particle Size Distribution (PSD) was determined, and particle morphology was characterized by SEM. Unfired binders were mixed as lime substitute in different percentages. Subsequent tests also included Thermogravimetric Analysis (TGA) to identify possible transformations during hydration and carbonation. Following this, four powders were chosen, and mixtures of alternative binder and water were prepared with hemp, at a ratio of 2:1 (binder:hemp). Compressive strength of the cured specimens was tested in an INSTRON 5982. The next stages included the characterization of mechanical and thermal properties of different LHC mixture sample blocks. Results showed that two of the chosen clays were more suitable for the production of LHC, and that replacing lime with alternative unfired binders affected LHC thermal properties negligibly, whereas using only alternative unfired binder instead of lime containing mixture improved compressive strength; yet such blocks were not stable when immersed in water. The samples with 50% lime and 50% unfired binder showed increased compressive strength up to 134% higher than only lime based LHC. Thermal conductivity of the different mixtures ranged between 0.055-0.07 W/m°K. These results refer to LHC samples produced with a density of 330 kg/m^3 and compressive strength of ~0.8-1.2 MPa and are fully compatible with AAC blocks of different producers available on the market today. An extensive presentation and discussion of this research stage may be found in Haik et al. (2020a).

The **second stage** aimed at investigating the actual compatibility with and possible exchangeability of conventional building materials with LHC. Towards this purpose four test cells with different LHC mixtures were built, alongside three identical cells built with conventional building materials – AAC, HCB and Expanded Polystyrene (EPS). All test cells (100/100/60cm) were built on solid concrete bases, with identical EPS slopped roofs with operable apertures (south facing 40/37.5cm, north facing 25/20cm) allowing solar heating in winter days and cross ventilative cooling during summer nights. Table 1 shows the properties of the materials used.

Table 1. Thermal properties and density of the tested materials.

	Material	Density [kg/m^3]	Thermal conductivity [W/m°K]	Specific heat capacity [J/kg°K]
Walls	LHC*	330	0.07	1400
	AAC	500	0.16	970
	HCB	1030	1.11	920
	EPS	43	0.033	1200
Floor	Concrete	2240	1.95	900

*Based on laboratory tests (Haik et al., 2020b). All other material properties based on ASHRAE database, incorporated in EnergyPlus.

The test cells were constructed at the Blaustein Institutes for Desert Research (BIDR) Campus of the Ben-Gurion University of the Negev (BGU), situated on the Negev Highlands, an arid desert approximately 475m above Mean Sea Level (MSL). Monitoring of indoor and outdoor air temperature, relative humidity, solar radiation, wind velocity and direction included hot, cold and transition seasons. Monitoring of each cell was done by three thermocouples – centre of indoor space, centre of external southern wall surface, centre of internal southern wall surface – and one HOBO UX100-03 temperature and relative humidity logger, placed at the centre of each cell, alongside the respective thermocouple. Parallel to monitoring test cell indoor conditions were simulated in EnergyPlus (DOE, 2020), in order to allow theoretical upscaling onto a full-size (100m^2) single family detached house under the same climatic conditions. Outdoor data were collected from the BIDR campus meteorological station.

Results showed that replacing lime with unfired binders hardly affected the behaviour of cells in terms of temperature and humidity. Best summer results were measured in the LHC cells (lowest temperature peaks) compared to those of the cells made with conventional materials, be they light, heavy or medium weight. Winter results showed a slightly better performance (highest night minima) in the AAC cell, though LHC was better than both HCB and EPS. Humidity measurements highlighted the LHC advantages in terms of “breathability”, i.e., gradual absorption and release of humidity in tandem with outdoor conditions. Here again, AAC had a marginal advantage in summer. Both summer and winter measurements showed LHC cell advantages in moderating extreme values, lowering diurnal fluctuation, and creating a time lag, compared to the cells built with conventional materials (Figure 1).

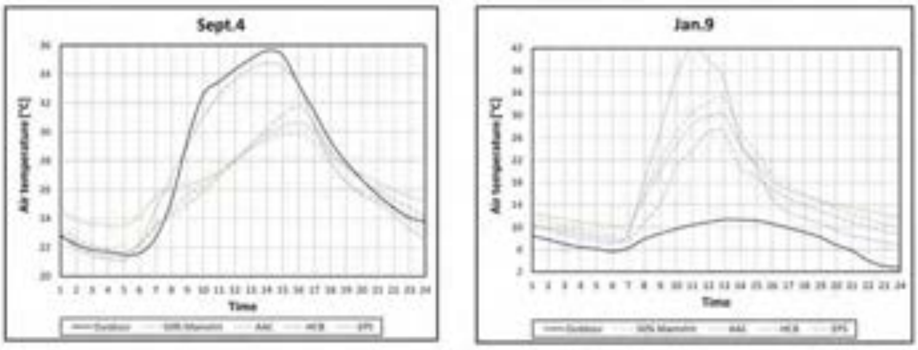

Figure 1. 24h data of outdoor and indoor air temperature during hot (left) and cold (right) season monitoring of representative LHC cell (50% unfired binder Mamshit) and conventional building materials (Haik et al., 2020b).

An extensive discussion of the experimental setup, monitoring and results analysis of this stage may be found in Haik et al. (2020b).

Monitoring and simulation results were in good agreement. This allowed to proceed to the next stage aimed at verifying the advantages of LHC as a full-size house building material, promoting improved indoor climate with significant OE savings both for heating and cooling.

The third and final stage of this program involved the upscaling and simulation of a full-size single-family house (100m^2, 10.0/10.0/2.9m) based on the previous stage results, allowing estimation of OE savings stemming from the use of LHC, compared with conventional building materials similar to those used in the comparison test cells. Thickness of walls and roofs of the simulated house model was assumed to be 0.2m/ South facing windows were designed to be of a total area of 13.5m^2, or 14.6% of the floor area, to comply with the 14-16% Window to Floor Ratio (WFR) stipulated by the Standard of Israel SI 5281 Sustainable Building Part 2 (SII, 2011) for the relevant climatic zone (C - Mountain Zone) to allow for direct solar gains in winter. The same standard sets a ratio of 0.7-0.8% north facing fenestration to floor area to provide sufficient summer night ventilation for thermal comfort and structural cooling. A door was located in the eastern façade. The floor was detailed as concrete, similar to that of the test cells. Windows were detailed as double glazed 3-13-3mm. Summer simulations included closed and externally fully shaded windows during the day (08:00-19:00), and fully open afterwards to allow cross ventilation estimated (based on measurements) at 10 ACH. In winter, south facing windows were fully exposed to solar radiation during the day, and fully insulated at night with EPS panels (as were the test cells in reality and simulations). Two different scenarios were simulated: a fully passive house, and an HVAC-supported house, the thermostat of which was set at 26°C in summer and 18°C in winter. Weather data were real ones measured at the BIDR meteorological station, used for the simulations of test cells in the previous stage. This was defined as preferable to the Typical Meteorological Year (TMY) file used by EnergyPlus, since weather peculiarities (extended hot season, unusual hot and cold spell fluctuations in transition seasons, etc.) may have a detrimental effect on the thermal behaviour of a building and its subsequent energy needs.

The passive building performed satisfactorily, maintaining indoors ~24°C while the windows are closed, approximately 8°C lower than the ambient (32°C). Indoor temperature peaks at ~26°C very close to the window opening time, when ventilation air movement can compensate for the higher air temperature. Indoor maxima were the lowest in the LHC building compared to all other buildings (AAC, HCB, EPS), while indoor minima were mostly similar to the outdoor minima, being higher only than the indoor minima in the HCB building. In winter, with solar gains and night window insulation, LCH and AAC temperatures are located between the EPS (highest) and the HCB (lowest), with a marginal advantage for LHC. Indoor maxima and minima in the LHC building maintain roughly an advantage of 9-11°C compared to the outdoor ones, reaching ~21°C during the day, and maintaining at least 15°C during the night.

The HVAC supported building's thermostat is set at 26°C in the summer and 18°C in winter. Following the same operation pattern for windows and shading, energy consumption was the lowest for LHC both in winter and summer, reaching an annual consumption of ~7kWh/m^2/year, surpassing the highest standards for nearly Zero Energy Buildings (nZEB) (BPIE, 2015). A detailed presentation of this stage of the research program may be found in Haik, Peled, Meir (2021).

Summarizing the different stages of this research program, it may be said with a high degree of certainty that LHC may be brought to a significantly lower EE and EC level by incorporating in it unfired binders to substitute lime. This does not affect its thermal properties while improving its compressive strength. The thermal performance of test LHC cells monitored in extreme desert climatic conditions was shown to be better than that of identical test cells built with conventional building materials (AAC, HCB, EPS). A parallel simulation of these cells alongside their monitoring showed good agreement between actual and simulated results. This allowed a theoretical upscaling from test cells to full-size house, which was then simulated for different building materials, both in passive and HVAC supported operation. In both cases, the thermal performance of LHC constructed building was shown to be better than that of the other buildings built with conventional materials. However, when simulating the building as being HVAC supported, it was shown that LHC brought it to a level higher than that stipulated by EU nZEB standards. Further investigation showed that, based on ISO 14040, Life Cycle Assessment (LCA) of the specific LHC mixtures and the structures built with them save up to 90% of the total energy (EE and OE) consumption and CO_2 emissions (Haik, Meir, Peled, 2023). Considering the fact some of the unfired binders were quarries waste, and hemp itself is an agro-industry waste byproduct, it can be concluded that Lime Help Concrete proves once again that “One man's trash is another man's treasure”, thus **closing another cycle**.

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References:

BPIE, 2015. Nearly Zero Energy Buildings Definitions Across Europe. Buildings Performance Institute Europe.

DOE, 2020. EnergyPlus (version 9). US Dept. of Energy, Building Technologies Office (BTO).

Haik, R., Bar-Nes, G., Peled, A., Meir, I.A., 2020a. Alternative unfired binders as lime replacement in hemp concrete. Construction & Building Materials 241(2020)117981.

Haik, R., Peled, A., Meir, I.A., 2020b. The thermal performance of lime hemp concrete (LHC) with alternative binders. Energy & Buildings 210(2020)109740.

Haik, R., Peled, A., Meir, I.A., 2021. Thermal performance of alternative binders lime hemp concrete (LHC) building: comparison with conventional building materials. Building Research & Information 49(7)763-776.

Haik, R., Meir, I.A., Peled, A., 2023. Lime Hemp Concrete with unfired binders vs. conventional building materials: a comparative assessment of energy requirements and CO_2 emissions. Energies 16, 708.

Hammond, G., Jones, C., 2008. Inventory of Carbon and Energy (ICE). Sustainable Energy Research Team, Dept. Mechanical Engineering, University of Bath, UK.

Lützkendorf, T., Foliente, G., Balouktsi, M., Wiberg, A.H., 2014. Net-zero buildings: incorporating embodied impacts. Building Research & Information 43(1), 62-81.

UN, 2017. World Urbanization Prospects 2018. United Nations, Dept. Economic and Social Affairs, Population Dynamics.

SII, 2011. Sustainable Building (Green Building): Requirements for Residential Buildings. SI 5281 Part 2. Standards Institute of Israel, Tel Aviv.

Why Edible Cities?

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ABSTRACT

The present linear urban systems are most probably an insurmountable obstacle to sustainability. Circular economy is the logical answer to this challenge. What is circular economy in cities? How does it affect engineering?

The first step is to reformulate the engineering goals. Conventional wisdom is to work at the improvement of supply, evacuation and treatment of material flows, even when we aim for sustainability. In a circular economy, material supply will be replaced by services, and it will be necessary to set standards for the recovery rate of materials, gradually increasing these recovery rates until close to 100%, independently of the sector or technology involved.

For water engineers increasing recovery rates means in a first approach to reuse all waters and ingredients, for solid waste management it implies extracting resources from waste, or urban mining. That is where edible cities come in handy. Loops need sources but also sinks. Productive urban green space can be a sink for water, nutrients, organic matter. Future engineers will need to make substance balances and design material flows, urban spaces and surfaces in a way to allow for the necessary sinks. Technologies will be chosen according to their ability to allow for resource recovery. This amounts to apply cleaner production principles everywhere, including households, and to learn from nature, which is best in loops.

"Waste" reuse is very little attractive to the general public, not least politicians. The term waste, as in wastewater, can be abandoned altogether. The EU stresses the "farm to fork" concept in its Green Deal. This can be extended to a "farm to fork to farm" loop – no "waste" anymore. But talking about loops, or circles, which have no beginning and no end, justifies to start at any point, not necessarily at what we consider waste. That is another advantage of edible cities, which stress the very positive aspect of food production.

In order to make an indent into our present linear systems, food production and more generally urban green has to become urban infrastructure for water and waste management, for cooling, building insulation, etc. Thus, urban green spaces and surfaces, not least productive ones, will have to be designed directly aiming at all these benefits, not just having them as possible collaterals. This needs comprehensive, transdisciplinary design approaches, involving many disciplines and sectors, including the users, who will be responsible for exploitation and maintenance. The future will be co-developed, co-designed and co-managed.

The loops need not only achieve high recovery rates but also be safe. Safety comprises human health hazards from substances involved, but also excessive heat, has to consider flood protection, as far as possible temper extreme events, provide healthy food, a stable economy, and protect other than human beings. Cleaner production will optimise technical and scale choices case by case, replacing the conventional one-system-fits-all approach. Economists are required to stabilise circular economies despite a shrinking resource demand.

The approach will greatly benefit from making all the positive aspects visible, as far as possible quantitatively, and tap into the various funding sources of the areas covered, water, food, waste, wellbeing, recreation, health, education, poverty alleviation, social stability, biodiversity, sustainable buildings (see ecolopes), etc. Quantifying the multiple benefits will be another important task of the joint engineering effort.

Plant-based biocides for the sustainable conservation of built heritage – Field experiments

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ABSTRACT

Introduction

Outdoor stone monuments are prone to various forms of biodeterioration due to the presence of moisture, nutrients, and favorable environmental conditions. Microorganisms, including bacteria, fungi, algae, and lichens, are the main agents of biodeterioration. They colonize the facades of monuments and form biofilms, creating an unsightly appearance that contributes to aesthetic damage, and lead to physical and chemical deterioration of monuments. These changes include erosion, discoloration, cracking, and loss of structural integrity (Mateus et al. 2013, Branysova et al. 2022). The biodeterioration of monuments poses significant challenges in the field of conservation and restoration requiring ongoing research and the implementation of effective strategies to mitigate the detrimental effects of living organisms on these valuable historical assets. Regular monitoring, maintenance, and cleaning of monuments are essential to remove biofilms, organic matter, and accumulated dirt, preventing and mitigating biodeterioration (Zhang et al. 2019). The use of biocidal treatments, such as environmentally friendly biocides or natural antimicrobial agents, can be considered for targeted control of microbial growth (Jeong et al. 2019, Kakakhel et al. 2019). In recent years, there has been a growing interest in exploring and developing plant-based biocides for the preservation of cultural assets. Plant extracts are generally considered safe for humans and the environment, as they are biodegradable and have usually low toxicity compared to synthetic chemicals (Jeong et al. 2019, Kakakhel et al. 2019). Many plant extracts have shown efficacy against a wide range of microorganisms, making them versatile in combating different types of biodeterioration. For instance, essential oils (EOs) from plants have been found to exhibit antimicrobial properties against bacteria and fungi commonly found on natural and cultural heritage sites (Argyri et al. 2021, Mateus et al. 2023, Mota et al. 2015). However, most of the studies performed were conducted in laboratory, so it is important to carry out field tests. The effectiveness of plant extracts as biocides can be influenced by several factors, including the concentration and composition of the extracts, the microorganisms targeted, and the environmental conditions. Field experiments provide valuable insights into the real-world application of plant extracts as biocides against stone biodeterioration. They help bridge the gap between laboratory studies and practical conservation practices, enabling conservationists and restoration experts to make informed decisions regarding the use of plant extracts for the preservation of stone-built heritage structures. Therefore, it is essential to conduct research and field tests to assess the real and long-term effectiveness of plant extracts in inhibiting microbial growth and preventing biodeterioration (Zhang et al, 2019).

The ongoing research aims to expand the knowledge of the antimicrobial properties of EOs, improve their formulation and application methods, and assess their long-term effectiveness in protecting cultural assets from biodeterioration. With this purpose, field experiments were conducted in the emblematic site of Portuguese cultural heritage, the Convent of Christ, to evaluate the *in-situ* efficacy of EOs derived from Portuguese endogenous plants, specifically *Thymus mastichina* (Tm), *Mentha pulegium* (Mp), *Foeniculum vulgare* (Fv), and *Lavandula viridis* (Lv). The Convent of Christ, located in the city of Tomar, Portugal, is a significant historical and architectural landmark. This magnificent monumental complex combines elements of Romanesque, Gothic, Manueline, and Renaissance styles, reflecting the evolution of Portuguese architecture over several centuries. The Convent of Christ has an immense cultural and historical importance, recognized as a UNESCO World Heritage Site since 1983, and today functions as a museum, allowing visitors to explore its architectural grandeur and learn about its historical significance.

Materials and Methods

The Tm, Mp, Fv, and Lv EOs were obtained by hydro-distillation in a Clevenger-type apparatus. The EOs composition was previously characterized through gas chromatography-mass spectrometry (Batista et al. 2022). The natural biocides based on EOs were prepared at a concentration of 20% v/v, by emulsifying each EO in an aqueous solution of the anionic surfactant sodium dodecyl sulphate (SDS) with a concentration of 0.2% w/v. As a positive control, the commercial biocide Biotin T was selected and used at a concentration of 1% v/v. While the negative controls included an aqueous solution of SDS (0.2% w/v) and water only. The biocides were applied to a limestone surface on the west facade of the Convent of Christ, more specifically on the inner face of the parapet of the Terrace of the Count, facing east. This location was chosen due to its easy accessibility for the works and being closed to visitors. The surface was visibly colonized and damage, as depicted in Fig. 1a). The test area was divided into different rectangular treatment areas, measuring 80 cm x 12 cm each, which included control areas. Separate areas were designated for the application of one, two, and three coats of the biocides (Fig. 1a). In the first week, the respective test rectangles, A, B, and C, were treated with a first coat of biocides and controls. The application was carried out using a brush, taking care to avoid drips (Fig. 1b). In the second week, a second coat of biocides was applied to test rectangles B and C. Finally, in the third week, a third coat of biocide was applied to test rectangles C. One week after the application of the last coat, the tested areas were cleaned to remove the dead biofilms and lichens. The mechanical cleaning method used water and a medium-hard CDS handwashing brush. Each test rectangle was cleaned for a duration of 1.5 minutes.

The treated areas were also subjected to sampling for evaluation of microbial colonization at the beginning and after the works. Microbial samples were collected through swabbing, and the degree of microbial colonization was analyzed using culture-based methods. In addition, the temperature and humidity of the local environment were monitored continuously for a duration of about one year. This monitoring aimed to assess the variations in temperature and humidity that could potentially impact the effectiveness of the biocide treatments and the growth of microorganisms.

Results and Discussion

Figure 1c) shows a picture of the test surface taken 5 weeks after the start of treatment. Table 1 provides a qualitative evaluation of the treatment effects, ranging from no effect to very high effect. The evaluation is based on both the removal of dead biofilms observed through visual inspection of the treated areas, compared to the negative controls, and the concentration of viable microorganisms cultivable in the laboratory. The following observations can be made: (i) From Fig. 1a), it can be observed that the rectangles closer to the floor exhibited a higher degree of damage and biofilms. For future tests, it is recommended to trace the tested rectangles vertically instead of horizontally to obtain better equity of the initial conditions; (ii) All the plant-based biocides, Biotin T, and the aqueous solution of SDS demonstrated biocidal activity when compared to the negative control of water; (iii) The biocidal efficacy increased with the number of applications; (iv) Under the tested conditions, all the EOs-based biocides exhibited a higher biocidal effect compared to the commercial biocide (Biotin T). However, it should be noted that the rectangles used for the Biotin T tests are close to the ground, initially also having a higher degree of contamination, and Biotin T was used at the lowest concentration recommended by the supplier. (v) Among the essential oils, *Thymus mastichina*, *Mentha pulegium*, and *Foeniculum vulgare* exhibited the highest field efficacy, followed by *Lavandula viridis*.

The biocidal potential of EOs-based biocides has already been demonstrated in laboratory tests using the agar disk-diffusion method, utilizing microorganisms isolated from stone structures of the Convent of Christ (Mateus et al., 2023). In the laboratory assays, all the tested EOs exhibited a lower biocidal activity compared to the commercial biocide Biotin T. However, under field conditions, all essential oils were found to be more effective than the commercial biocide.

Figure 2. Pictures of the tested site on the inner face of the parapet of the Terrace of the Count. (a) Rectangular tested areas for the application of one (A), two (B) and three coats (C) of biocides and controls specifically: Tm (1), Mp (2), Fv (3), Rv (4), SDS (5), Biotin T (6), water. (b) Application of the biocides and controls in the first week. (c) After cleaning, five weeks after the beginning of the application of the first coat.

Table 1. Qualitative evaluation of the biocidal effect ("–" indicates no effect, "+" low effect, "++" medium effect, high effect, and "++++" very high effect).

Biocide	Tm	Mp	Fv	Rv	BT	SDS	Water
Biocide effect	++++	++++	++++	+++	++	+	–

The biodeterioration of exterior facades of monuments is influenced by several factors, including climate, pollution, microclimate, exposure to sunlight and maintenance practices. Temperature and moisture are crucial factors as they can promote microbial growth and facilitates the colonization of organisms on the monument's surfaces. Fig. 2 shows the results obtained for the monitored environmental temperature and humidity. Significant daily temperature gradients were recorded during all months, while high humidity levels were recorded mainly during winter. Despite the temperature and humidity gradients, the range of values recorded is favorable to the development of the biota throughout the year, as expected for a Mediterranean climate.

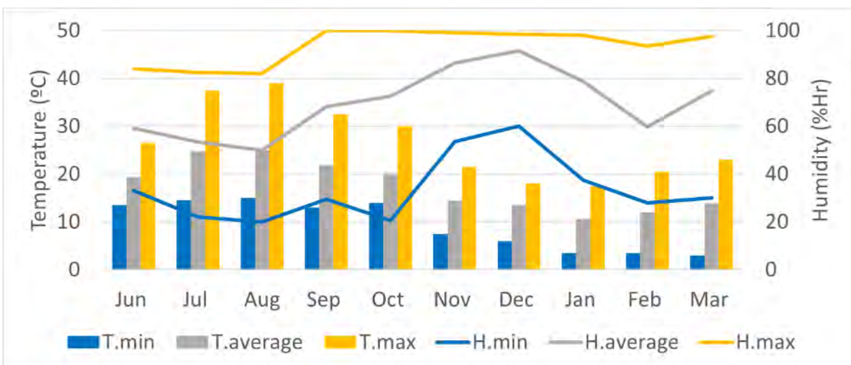

Figure 2. Minimum (min), average and maximum (max) monthly temperature (T) and relative humidity (H), from June 2022 to March 2023.

These findings confirm that biocides based on plant essential oils are effective under real conditions, even more so than in laboratory assays. This can be attributed to the fact that many microorganisms responsible for biodeterioration, particularly symbiotic species that form biofilms, are not easily cultivable in the laboratory. Moreover, it is challenging to simulate the true environmental conditions in the laboratory, which can significantly influence the growth of microorganisms and the effectiveness of biocides. These results underscore the importance of conducting field tests to validate the efficacy of biocides in real-world settings.

Conclusions

It can be concluded that biocides derived from the essential oils of *Thymus mastichina*, *Mentha pulegium*, *Foeniculum vulgare*, and *Lavandula viridis* demonstrate effective inhibition of the growth and activity of microorganisms in field conditions. These EOs possess natural antimicrobial properties, and exhibit broad-spectrum activity, making them a promising alternative to synthetic biocides for safeguarding cultural assets against biodeterioration. Moreover, the utilization of plant extracts presents a promising and eco-friendly approach to preserving and protecting cultural heritage.

Continuing the research and development in this field will contribute to a better understanding and utilization of plant extracts as potent biocides for the long-term protection of cultural heritage. Ongoing tests are also being conducted to assess the environmental ecotoxicity of essential oils and their impact on the support materials. Future work should focus on evaluating the long-term biocidal effects and conducting field tests using biocidal preparations with lower concentrations of essential oils.

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References:

Argyri, A.A., Doulgeraki, A.I., Varla, E.G., Bikouli, V.C., Natskoulis, P.I., Haroutounian, S.A., Moulas, G.A., Tassou, C.C., Chorianopoulos, N.G., 2021. Evaluation of Plant Origin Essential Oils as Herbal Biocides for the Protection of Caves Belonging to Natural and Cultural Heritage Sites. Microorganisms, 9, 1836, 9,1836. https://doi.org/10.3390/microorganisms9091836.

Branysova, T., Demnerova, K., Durovic, M., Stiborova, H., 2022. Microbial biodeterioration of cultural heritage and identification of the active agents over the last two decades. Journal of Cultural Heritage, 55, 245-260, https://doi.org/10.1016/j.culher.2022.03.013.

Baptista, C., Santos, L., Amaral, M.E., Silva, L., 2022. Chemical Characterization of Essential Oils With a Biocide Base for Conservation and Restoration. In: 1st International FibEnTech Congress (FibEnTech21) New opportunities for fibrous materials in the ecological transition, KnE Materials Science, pp 80-90, https://doi.org/10.18502/kms.v7i1.11611.

Jeong, S.H., Lee, H.J., Kim, D.W., Chung, Y.J., 2018. New Biocide for Eco-friendly Biofilm Removal on Outdoor Stone Monuments. Int. Biodeter. Biodegr. 131, 19–28, https://doi.org/10.1016/j.ibiod.2017.03.004.

Kakakhel, M., Wu, F., Gu, J., Feng, H., Shah, K., Wang, W., 2019. Controlling Biodeterioration of Cultural Heritage Objects With Biocides: A Review. Int. Biodeterior. Biodegrad. 143, 104721, https://doi.org/10.1016/j.ibiod.2019.104721.

Mateus, D.M.R., Silva, R., Costa, F., Coroado, J.P.P., 2013. Microbiological Diversity in the Unfinished Sacristy Building of the Convent of Christ, Tomar, and Evaluation of its Biocide-based Control. Conserv. Patrim. 17, 11–20 https://doi.org/10.14568/cp2012005.

Mateus, D.M.R., Costa, F.M.C., Triães, R.P., 2023. Essential Oils of Plants as Biocides Against Microorganisms Isolated from Portuguese Convent of Christ in Tomar. In: Yang, Z. (eds) Environmental Science and Technology: Sustainable Development. ICEST 2022. Environmental Science and Engineering. Springer, Cham. https://doi.org/10.1007/978-3-031-27431-2_10.

Mota, A., Martin, M., Arantes, S., Lopes, V., Bettencourt, E., Pombal, S., Gomes, A., Silva, L., 2015. Antimicrobial Activity and Chemical Composition of the Essential Oils of Portuguese *Foeniculum vulgare* Fruits. Natural Product Communications 10, 673–676 https://journals.sagepub.com/doi/pdf/10.1177/1934578X1501000437.

Zhang, G., Gong, C., Gu, J., Katayama, Y., Someya, T., Gu, J., 2019. Biochemical Reactions and Mechanisms Involved in the Biodeterioration of Stone World Cultural Heritage Under the Tropical Climate Conditions. International Biodeterioration & Biodegradation, 143, 104723, https://doi.org/10.1016/j.ibiod.2019.104723

Advancing Circular Economy in the Built Environment: The CircularB Action

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Keywords: building's circularity, circular value chain, sustainable development goals, circularity challenges, building information modelling, sustainability frameworks

ABSTRACT

General Description of the COST Action CA21103 CircularB

With rising concerns over the negative environmental and natural resource impacts of buildings and their associated activities, governments and societies worldwide have been actively seeking more efficient and sustainable construction practices. In response to this need, the concept of circular economy (CE) has emerged as an innovative approach with vast potential for application in the construction industry and the urban built environment (Anttonen *et al.*, 2018). By optimizing building usage, preserving service life of systems and components, and integrating nature-based solutions, CE offers promising avenue towards sustainable development. In line with the new European Circular Economy Action Plan (ECEAP) introduced in 2020, various efforts have been made to incorporate circular resource thinking into construction practices and sustainability frameworks, such as Level(s). Despite recent progress, there remains a shortage of standardised tools and activities that fully realise the potential of circularity in construction (Cambier *et al.*, 2020; Askar *et al.*, 2022). There is a critical need for a common international framework that implements circularity, classifies buildings accordingly, and assesses the level of realisation of the ECEAP (Askar *et al.*, 2022). Recognising this gap, the CircularB Action initiative aims to develop a common international framework of a circularity rating tool with Key Performance Indicators (KPIs) based on current best practices of CE in the construction sector, state-of-the-art technologies, and the principles outlined in the ECEAP. The framework of the CircularB design-support and rating tool allows local adaptation and application by different COST countries. By developing a benchmark database that considers each country's unique conditions, construction practices and design culture and traditions, the tool enables its direct utilisation. This empowers designers to develop more sustainable buildings while aiding national and local governments in assessing and promoting their circular economy targets. In addition to the rating tool, CircularB will identify construction, assembly, adaptability, deconstruction and business model strategies and guidelines. These recommendations will serve to enhance circularity in both new and existing buildings while fostering knowledge sharing among stakeholders – including building professionals and industrial manufacturers. By disseminating best practices, CircularB aims to create a collaborative environment that promotes the widespread adoption of CE principles. To facilitate better-informed design decisions and automated circularity assessment, CircularB will integrate the rating tool into the Open Building Information Modelling (BIM) workflow. This integration will enhance the efficiency of the value chain management, provide accessible data for stakeholders, and enable circular feedback loops using central BIM models. By leveraging BIM technology, CircularB aims to streamline the integration of circular economy principles into the design and construction processes, fostering a more sustainable built environment.

The Challenge and Progress Beyond the State-of-the-Art – The Aims and Objectives of the COST Action CircularB

In recent years, the concept of circularity has gained significant attention in the pursuit of sustainable practices. The need for a comprehensive and inclusive approach to circularity conception has become apparent (Geissdoerfer *et al.*, 2017; Nikolaou *et al.*, 2021). In response, CircularB aims to establish a network of interdisciplinary expertise that promotes broader perspective, debates and discussions surrounding circularity to achieve sustainable development without compromising other economic, environmental and social aspects. By bridging the gaps in existing circularity rating tools and fostering a dynamic participatory and practice-oriented approach, CircularB strives to propel progress beyond the state-of-the-art. Current

circularity practices predominantly focus on specific and isolated aspects such as circular materials development and management of CDW (construction and demolition waste), without considering a holistic approach (Adams *et al.*, 2017; Anttonen *et al.*, 2018; Askar *et al.*, 2022). Essential principles of CE, such as slowing the loop or narrowing the loop, are often overlooked (Askar *et al.*, 2022). The narrow focus leads to conflicts and potential trade-offs when integrating multiple aspects into current applications. CircularB COST Action recognises the importance of building a bridge between theory and practice to overcome these challenges. One of the primary objectives of CircularB is to develop KPIs that assess circularity in buildings considering data requirements and compatibility within the holistic perspective of construction sustainability design and assessment. CircularB addresses these prospects by adapting a complementary set of circularity to common frameworks such as the Level(s) developed by the European Commission. By integrating circularity into established assessment tools, CircularB aims to promote a lifecycle thinking and end-of-life perspective, allowing for the development of case-sensitive trade-offs. The involvement of representative stakeholders with interlocking specialities will ensure closing the loop of supply and demand, considering all stages of the building lifecycle. Academic and industrial actors' involvement will enable the detection of specific circular business models and associated benefits in building activities, ultimately supporting the creation of economic value. To enable efficient information transfer among partners, CircularB will explore clear workflow management and match-making circularity-oriented tools. These tools will not only monitor the efficient exchange of information but also enable stakeholders to develop new insights and make better-informed design choices. The engagement of involved stakeholders is crucial in promoting efficient information flows, participatory conversations to develop viable business model developments focusing on value proposition, customer involvement and supply chain management (Cambier *et al.*, 2020).

CircularB COST Action main research coordination objectives focus on:
- Coordination and analysis of current policies in the building design and use, and real estate industry to identify opportunities and barriers for implementing CE principles.
- Collection of data on innovative construction techniques, novel technologies and circular materials, for new and existing projects; including rehabilitation, adaptive reuse methods, and resource recovery.
- Establishment of guidelines for implementing circularity measures in buildings and translating CE principles into actionable strategies.
- Development of a common circularity framework incorporating criteria and KPIs to assess materials, components and buildings, integrating it with BIM workflows, aligning with existing assessment tools like Level(s), and customizing it to suit regional contexts, including local traditions, culture, materials, and methods.
- Exploration of innovative business model ideas to incorporate CE into buildings construction workflow and examination of market applications for the KPIs framework.
- Elaboration on adaptive resource strategies to predict adequate pathways for current building stock, facilitating targets for material and resource recovery.

Main capacity-building objectives of the Action focus on:
- Fostering stakeholders' capacity building and knowledge exchange by developing new skillsets and approaches to CE in the value chain from different regions.
- Stimulating policymakers and communities in CE adoption by raising awareness about the negative consequences of the linear economy and involving them in the development of applicable CE strategies.
- Enhancing collaboration and alliances among different sectors – *i.e.*, material manufacturing, supply chain, project, construction, demolition and waste industry, academia, and governments – to develop tools, strategies and methodologies for CE participatory implementation in the built environment.
- Supporting early-career researchers and investigators by providing opportunities for them to contribute to CE projects and challenge the current linear model.
- Establishing a knowledge-sharing platform bringing entire value chain stakeholders and promote dissemination by creating an online platform of best practices, guidelines, and success stories, organizing workshops, training schools, and events to enhance knowledge and promote participatory activities, and publishing joint scientific and technical papers while facilitating knowledge transfer between scientific research and industry through collaborative discussions.

A complete list of specific objectives can be found in the Memorandum of Understanding (MoU) of the COST Action CA21103 CircularB (CircularB, 2022), available at https://www.cost.eu/actions/CA21103/.

CircularB Implementation – Description of the Working Groups, Tasks, Deliverables, and Milestones for the First Year of the Action

The CircularB COST Action aims at delivering a holistic approach to circular buildings – including all technological, societal, legal, economic, and environmental aspects. To cover all these facets, the research is divided into four proposed Working Groups (WGs) (Figure 1).

Scientific development (WG1, WG2, WG3):

- WG1: Circularity strategies and best practices – WG1 focuses on developing inventive and effective approaches in implementing and evaluating circular strategies and materials within design and construction, and identifying best existing practices, advantages, and technical barriers and concerns. WG1 is dedicated to creating integrated and tailored design and engineering solutions for buildings that are both dynamic in nature. This involves tackling circularity challenges related to resource efficiency and waste prevention by incorporating key concepts such as design for adaptability (DfA), design for disassembly (DfD), design for change (DfC), and reversibility. These principles are applicable to both new and existing buildings, with a strong emphasis on mitigating environmental impacts throughout the process (CircularB, 2022).
- WG2: Circular value chain and stakeholder engagement – WG2 is dedicated to analysing the full value chain associated with circular materials, components, and buildings. The primary objective of this WG is to establish a collaborative platform that brings together various stakeholders form academia, industry, suppliers, governmental bodies local authorities and policymakers, construction professionals and the general public. This interdisciplinary approach aims to foster participatory dialogue and engagement with the involved stakeholders which ensures effective management of a circular value chain and the creation of potential loops. The group focuses on identifying opportunities for collaborative patterns, decision-making activities, and the development of new business models that take into account the diverse requirements and interests of the stakeholders involved (CircularB, 2022).
- WG3: Circular KPIs framework – WG3 is focused on the identification and development of robust and replicable criteria and indicators for measuring the circularity index of buildings. This WG aims to establish relevant KPIs that can be uniformly applied across different countries. These KPIs will be based on the best practices and action plans outlined in national and international CE initiatives, as well as governmental reports. To ensure a comprehensive coverage, the KPIs will be categorised into governmental/institutional, environmental, social, economic, and technical dimensions. This grouping allows for a holistic assessment of the circularity of buildings and facilitates the proposal of an international rating framework. The intention is to evaluate the sustainability added value of buildings by incorporating circular principles. This international system framework will complement existing recognized sustainability schemes such as the common European framework for sustainability Level(s), SBTool, and others. The ultimate goal is to provide decision-makers with reliable tools to support informed decision-making processes based on a detailed circular assessment (CircularB, 2022).

Monitorisation, coordination, communication and dissemination (WG4):

- WG4: Dissemination and results communication – WG4 is responsible for maximising the impact of CircularB through a range of dissemination, communication, and outreach activities. These activities include managing the CircularB Action webpage, engaging with the audience through social media channels and distributing regular newsletters. This WG also actively seeks opportunities to expand the network of the Action by establishing connections with other transdisciplinary networks and relevant stakeholders and partners. The primary objective of WG4 is to ensure that the knowledge and outcomes generated by CircularB reach a wide audience. By leveraging various communication channels and platforms, the WG4 aims to effectively disseminate information, engage with the public, and create awareness about circularity in the built environment (CircularB, 2022).

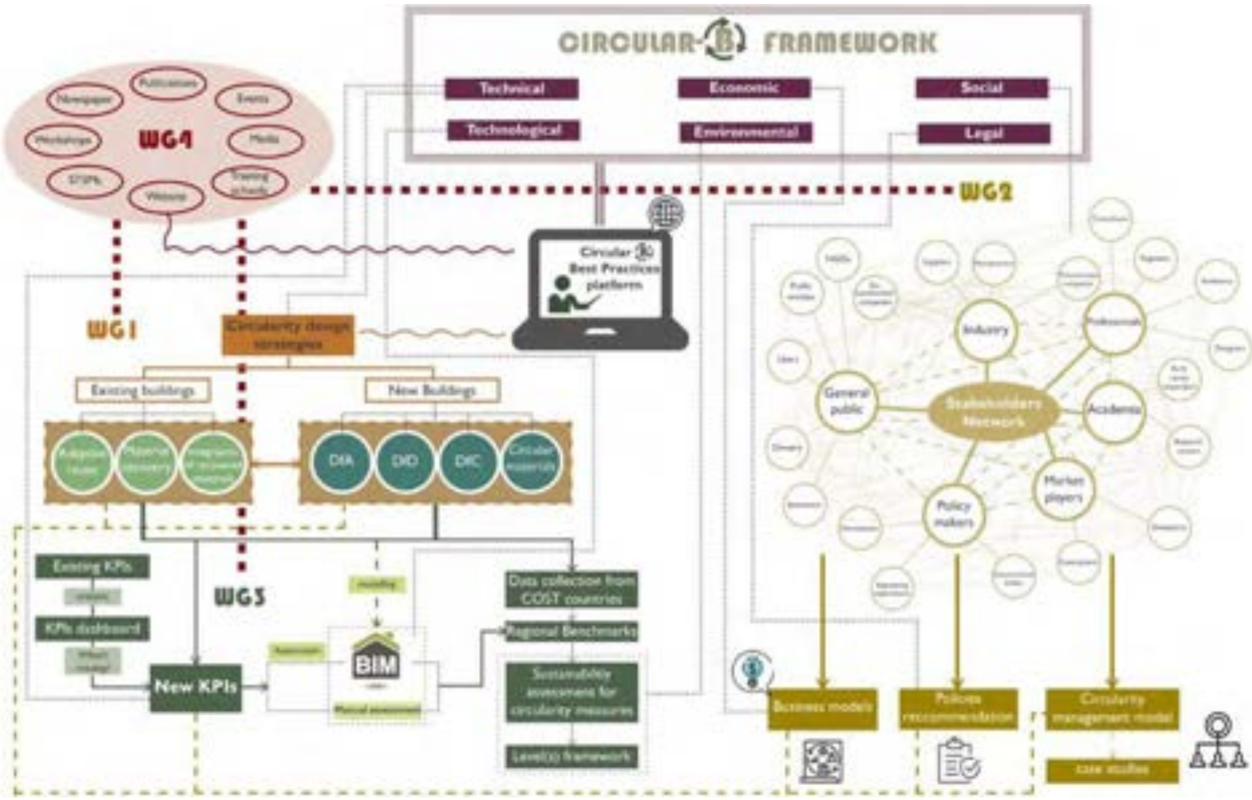

Figure 1. CircularB Working Groups links and interactions (CircularB, 2022).

Deliverables 1 and 2 (D1 and D2) developed within the Year 1 and Milestone 1 on the *State-of-the-art synthesis* of the CircularB Action will be presented: D1 on identification of *Communication, dissemination and networking strategy* (WG4); and D2 on the compiled *State-of-the-art report* (WG1, WG2, WG3) focus on (i) existing circularity strategies for buildings, (ii) policies and legal support, (iii) stakeholders' roles and relationships, and (iv) circularity criteria, KPIs and available international assessment frameworks.

Acknowledgements

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References:

Adams, K.T., Osmani, M., Thorpe, T., Thornback, J., 2017. Circular Economy in Construction: Current Awareness, Challenges and Enablers. Proceedings of the Institution of Civil Engineers - Waste and Resource Management 170 (1), 15–24, https://doi.org/10.1680/jwarm.16.00011

Anttonen, M., Lammi, M., Mykkänen, J., Repo, P., 2018. Circular Economy in the Triple Helix of Innovation Systems. Sustainability 10 (8), 2646. https://doi.org/10.3390/su10082646

Askar, R., Bragança, L., Gervásio, H., 2022. Design for Adaptability (DfA) – Frameworks and Assessment Models for Enhanced Circularity in Buildings. Applied System Innovation 5 (1), 24. https://doi.org/10.3390/asi5010024

Cambier, C., Galle, W., De Temmerman, N., 2020. Research and Development Directions for Design Support Tools for Circular Building. Buildings 10 (8), 142, https://doi.org/10.3390/buildings10080142.

CircularB, 2022. Memorandum of Understanding for the Implementation of the COST Action "Implementation of Circular Economy in the Built Environment" (CircularB) CA21103. https://circularb.eu/repository/action-documents/

Geissdoerfer, M., Savaget, P., Bocken, N.M.P., Hultink, E.J., 2017. The Circular Economy – A new sustainability paradigm? Journal of Cleaner Production 143, 757–768. https://doi.org/10.1016/j.jclepro.2016.12.048

Nikolaou, I.E., Jones, N., Stefanakis, A., 2021. Circular Economy and Sustainability: The Past, the Present and the Future Directions. Circular Economy and Sustainability 1, 1–20. https://doi.org/10.1007/s43615-021-00030-3

Biomimicry in architectural design in a holistic design process

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Keywords: bionic, architecture, biomimicry, interdisciplinary, urban design

ABSTRACT

In times of climate crisis, a sustainable approach to architectural design is important. Particular results can be achieved through the implementation of bionic design, biomimicry, which allows broad inspiration from the natural world. Bionics, as an interdisciplinary field of science, studies the way living organisms and processes in nature function, and aims to transfer these observed elements by means of models created into technology. As a result, it becomes possible to search for solutions that minimize energy and matter consumption on the model of living organisms that have been shaped by evolution. This allows emergent solutions for ecological design to emerge, which can be manifested in a variety of ways leading to holistic design combining many of the contemporary trends in ecological design including circular economy. The analysis carried out of the various forms of application of the bionic approach in holistic architectural and urban design allows the identification of the basic elements of a design process in which the main objective is to achieve sustainable construction, in which the design approach pursues pro-ecological goals, e.g. minimization of material consumption, metabolic cycle and reuse of materials, minimization of waste, carbon footprint, sustainable solutions for building materials and systems as well as an interdisciplinary approach that allows the creation of synergistic solutions for architectural and technical structural forms.

References:

Nowak A. 2017. Kształtowanie bionicznych powierzchni strukturalnych w architekturze współczesnych elewacji. PhD thesis at the Faculty of Architecture of the Warsaw University of Technology

Pawlyn M., 2011. Biomimicry in architecture, London.

Scarr G., 2018 .Biotensegrity. tensegrity in biology.< http://www.tensegrityinbiology.co.uk> access: 30.01.2018

Session A2: Social dimension of NBS

Methodological Approach for assessing the effectiveness of co-creation processes of Nature-based solutions: The case-study application of CLEVER Cities project.

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Keywords: co-creation, nature-based solutions, urban planning, evaluation, urban greening

ABSTRACT

Selected Conference Topic: *Circular design and integrated planning approaches for increased resiliency*

Since 2018, the CLEVER Cities project has put in place an inclusive co-creation pathway that aims at engaging stakeholders (in particular citizens, civil society, public and private stakeholders) in decision-making processes for implementing Nature-based Solutions (NBS) within uprunning large-scale urban regeneration projects in three European cities, namely Hamburg, London and Milan.

The cities involved in the project, therefore, engaged in the co-creation process, testing, and questioning about the effort in terms of time and human resources used to implement the urban greening measures within their urban planning practices. The CLEVER Cities co-creation pathway was initially ideated as a linear blueprint of complete co-creation phases: co-planning, co-design, co-implementation, co-development, and upscaling (Mahmoud and Morello 2021). In fact, with a view to institutionalizing and replicating the co-creation processes of urban green areas, it is important for local governments to equip themselves with tools to be able to evaluate the added value of a shared process. However, in the literature and in the practice of shared governance, monitoring, and evaluation (M&E) tools relating to the effectiveness of co-creation processes are lacking majorly (Tzoulas et al. 2021; Galan et al. 2023) .

The scope of this research, hence, is to highlight and provide evidence on the importance of conducting an evaluation for co-creation as an added value from the actual implementation of NBS in the collaborative environment of the 'CLEVER Action Labs' (CALs), to help demonstrating the value added in embarking on a shared governance approach around urban greening transformations and a better citizen engagement (Nguyen et al. 2022). Hence, a systematic approach to gather information on each city's pathway along the co-creation process was developed for defining and refining a set of indications, in order to evaluate: 1) the commitment of the involved participants to the process, 2) the realistic and tangible social and environmental impacts resulting from the project implementation, and 3) the co-creation procedure and process itself, how it changed along its course of the project lifetime.

Within the context of Urban Innovation Partnerships[1] (UIPs) of CLEVER Cities project, different workshops, one-to-one interviews, and surveys were used to gather opinions and feedback from cities' leaders and co-creation facilitators' teams on the possible criteria of assessment from March 2020 onwards, utilizing a reflexive method till September 2022, see Figure 1. Three sets of indicators mainly prioritizing 1) stakeholder engagement, 2) shared governance model and 3) co-design activities were selected. A learning by doing approach (as an empirical approach) was adopted to structure the results from the framework implementation based on two categories of qualitative and quantitative indicators: procedural indicators (looking at the quality of the process itself in achieving its goals) and impact indicators (that address the expected results and impacts originated from the co-creation activities).

From the workshops with cities in a concurrent timeline with the project co-creation processes, two sessions were held to validate the results from the surveys and the previous analysis based on cities exchanges. Afterwards, two main categories are transversally embedded for measurement: the stakeholder engagement and the shared governance process within the two first project phases, namely the partnership establishment and the co-design phases, see results section. The measurements in these two categories are meant to be reflecting the overall co-creation process in the three cities and are not entailed to a specific phase (it could

[1] The UIP is the local public private partnership cluster of actors and stakeholders that carry out the implementation of the project in the local context of each city.

happen on a UIP scale or a CAL scale – any scale more detailed than that should be aggregated). The first column (categories) refers to macro areas of interest such as 1) stakeholder engagement, 2) shared governance model and 3) co-creation pathway (co-design phase so far), see Table 1.

Each city's evaluation effect is translated into a score board to assess its own co-creation pathway performance. There is no pre-defined success or failure threshold. The general idea is to set a baseline for a set of key performance indicators for assessing co-creation processes towards a future verification and validation of the methodological framework.

The concept behind this methodological approach is not to compare between what 'happened' throughout co-creation experiences in the CLEVER Cities, but rather to understand what added value co-creation and shared governance can provide to the governance of cities and advance the models and the possible focus on social learnings from co-creation processes (Ziervogel et al. 2022). The analysis carried out in this research will highlight the evidence-base from a possible co-creation assessment methodology that takes advantage from the experience of cities towards assessing the effectiveness of such experiences to be replicated in further urban planning practices.

Graphical representation of the abstract

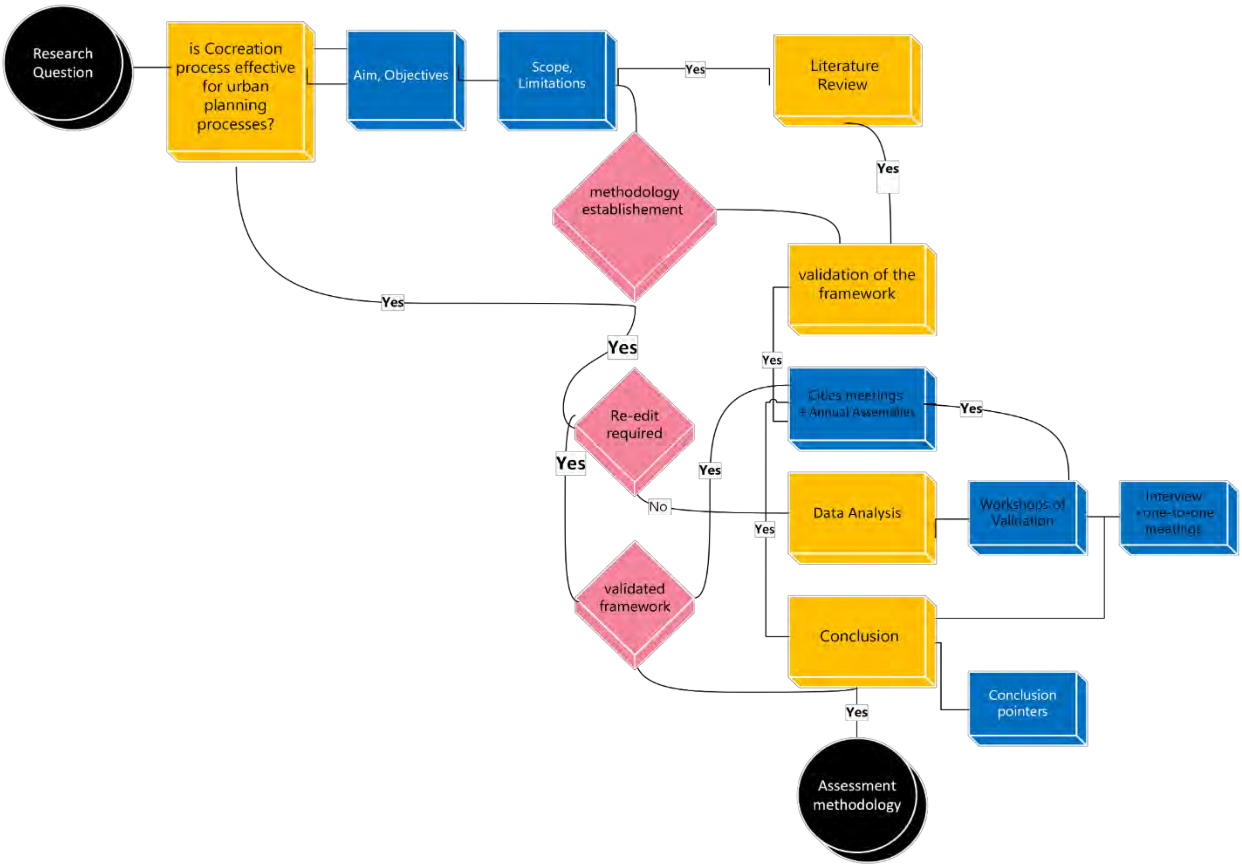


Figure 0: Methodological flowchart for the development of the assessment framework of co-creation based on empirical evidence.

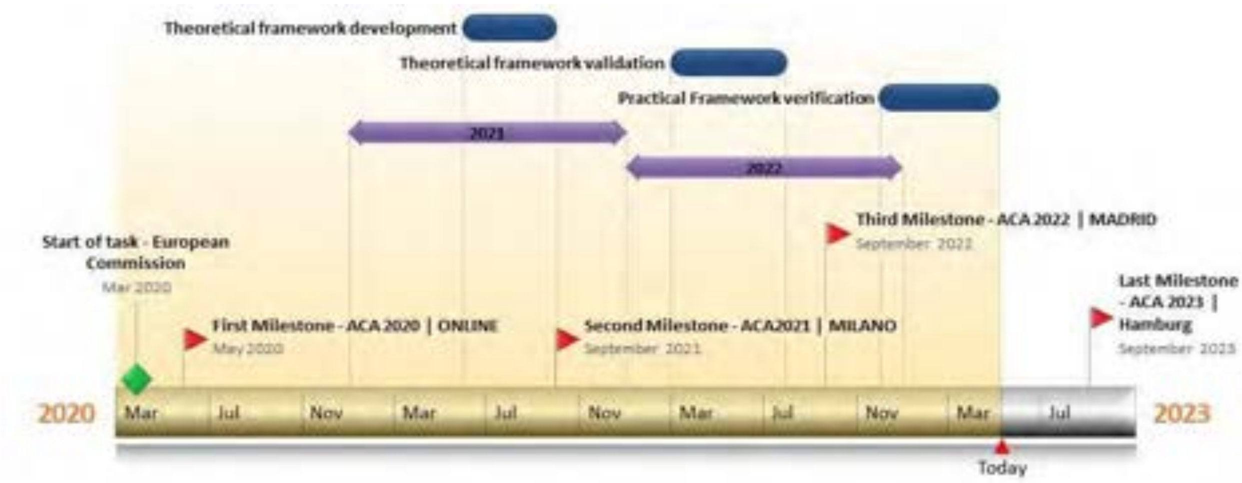
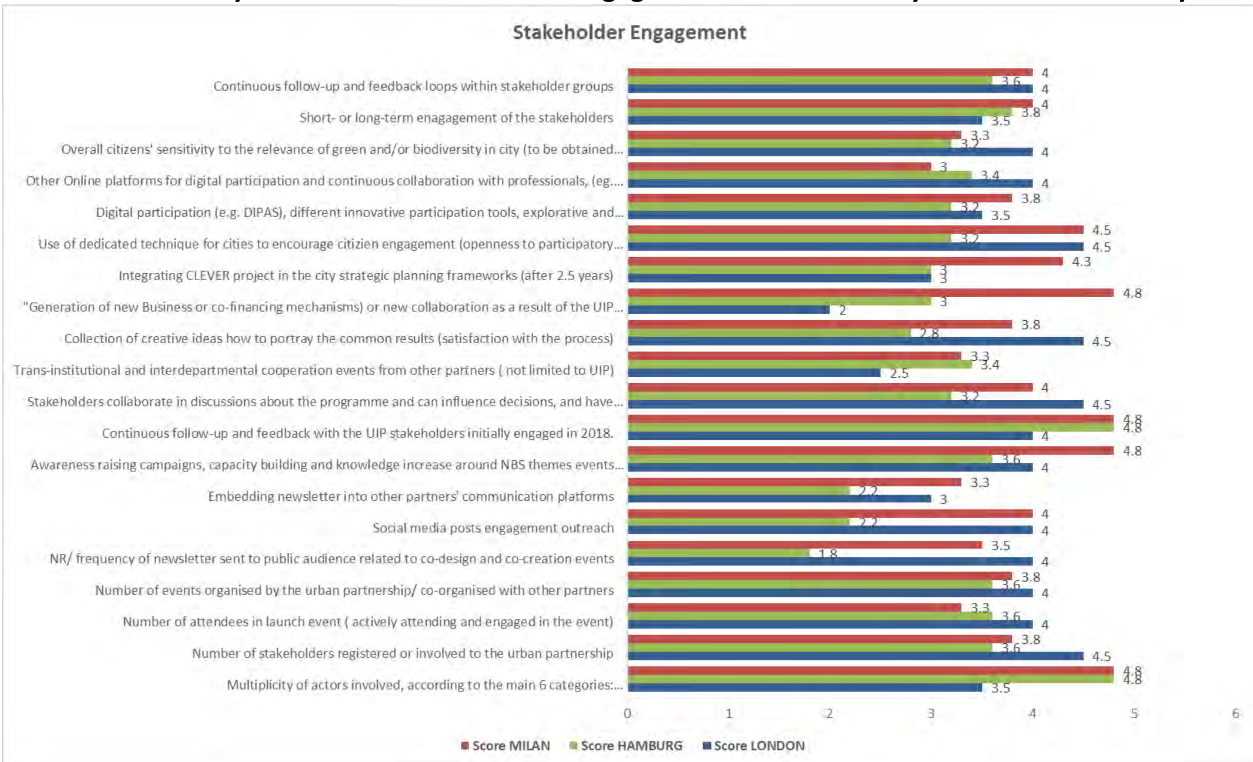


Figure 4: Timeline of the research project development

Table 1: Evaluation Matrix – score board – sample from cities

MACRO Categories	MICRO categorization Level of information	KEY INDICATORS Questions for cities - Guiding Topics of interest for cities	Units of measurement	MILAN			
STAKEHOLDER ENGAGEMENT							
Stakeholder engagement	UIP (urban innovation partnership) and CAL (CLEVER Action lab)			UIP	CAL1	CAL2	CAL3
SHARED GOVERNANCE MODEL							
Shared governance model	based on the overall of the co-creation pathway						
CO-CREATION PATHWAY							
CO-DESIGN	based on the overall of the co-creation pathway						

Results: Preliminary results from Stakeholders engagement indicators analysis 1st indicators analysis



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References:

Galan J, Galiana F, Kotze DJ, et al (2023) Landscape adaptation to climate change: Local networks, social learning and co-creation processes for adaptive planning. Global Environmental Change 78:. https://doi.org/10.1016/j.gloenvcha.2022.102627

Mahmoud I, Morello E (2021) Co-creation Pathway for Urban Nature-Based Solutions: Testing a Shared-Governance Approach in Three Cities and Nine Action Labs. In: A. Bisello et al. (ed) Smart and Sustainable Planning for Cities and Regions. Springer International Publishing, pp 259–276

Nguyen HT, Marques P, Benneworth P (2022) Living labs: Challenging and changing the smart city power relations? Technol Forecast Soc Change 183:121866. https://doi.org/10.1016/j.techfore.2022.121866

Tzoulas K, Galan J, Venn S, et al (2021) A conceptual model of the social–ecological system of nature-based solutions in urban environments. Ambio 50:335–345. https://doi.org/10.1007/s13280-020-01380-2

Ziervogel G, Enqvist J, Metelerkamp L, van Breda J (2022) Supporting transformative climate adaptation: community-level capacity building and knowledge co-creation in South Africa. Climate Policy 22:607–622. https://doi.org/10.1080/14693062.2020.1863180

Why there are not more Nature-Based Solutions implemented in European cities: A Stakeholder Analysis

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Keywords: semi-structured interview, urban circularity challenges, built environment, green infrastructure, resource recovery, urban agriculture

ABSTRACT

This communication analyses the main challenges and benefits deriving from the implementation of nature-based solutions (NBS) in urban settings from several aspects within the categories of sustainable and circular use of urban water and management, resource recovery, urban agriculture, climate change mitigation and adaptation, and the different scales of the urban built environment (Atanasova *et al.*, 2021; Langergraber *et al.*, 2021a,b) (Figure 1). Three main research questions are addressed: (1) Which are the most popular NBS in urban planning policies? (2) What are the main expectations, benefits and challenges regarding the implementation of NBS according to local stakeholders? and, (3) Which are the narratives related to NBS in different urban policy contexts? This contribution presents six exploratory case studies from cities across Europe, which were selected to mirror the geographical heterogeneity, presenting the diversity of practices in NBS implementation at the city level (Figure 1).

Figure 1. Urban circularity challenges addressed by nature-based solutions in selected European cities.

Introductory Background and Research Challenge

Climate change challenges and consequences in urban settings – *e.g.*, degradation of ecosystems, resource depletion, and threats to biodiversity enrichment, among others – are amplified by current and expected cities' growth and development. Nature-based solutions (NBS), as blue-green spaces, infrastructures, and technologies have the capacity to mitigate these issues by harnessing natural processes and delivering multiple ecosystem services in the urban environment (Kabisch *et al.*, 2016; Langergraber *et al.*, 2021a,b). To effectively coordinate and benefit from NBS , they must be designed and implemented from the earliest stages of the urban planning development. In recent years, many European cities explicitly recommended the application of NBS as a key driver to put in practice sustainable planning policies, strategies and frameworks to boost the resiliency of urban communities. Nonetheless, the mainstreaming of NBS in official municipal urban plans and programs still appears blurred and scarcely debated. Urban actors, as local stakeholders, are seen as crucial filters to turn the European Union strategies into practical policies aimed at transforming cities into sustainable and climate-resilient ecosystems while harnessing the potential of NBS (Raymond *et al.*, 2017). From municipalities to citizens' associations, from non-governmental organisations (NGOs) to private companies engaged in innovation and environmental sustainability, local actors decide which NBS are the most suited, being able to create narratives to promote the use of natural solutions in their implementation context. Hence, local stakeholders can support the successful implementation and their economic and social benefits of NBS in cities, by abandoning the silos approach for constructive and cooperative interaction with policy makers and practitioners (Nika *et al.*, 2021). Despite their importance, practical applications of NBS in urban planning, along with their benefits' expectations, challenges, and services perceived by local stakeholders are still scarcely investigated. The present communication aims to understand how city councils use the tools and methods related to NBS in urban planning, and how complementarity the elements and principles of circular economy (CE) appear in their everyday practices.

Selection of Case Study Regions, and Applied Research Methodology

The information about modes of NBS implementation in local planning was obtained by interviewing stakeholders – *i.e.*, decision-makers, planners, researchers, NGOs, businesses, and representatives of local civic organisations – who stated their experiences and expertise on applying NBS strategies in their respective cities. This stakeholder analysis was conducted in six European cities: Reykjavik (Iceland), Ljubljana (Slovenia), Córdoba (Spain), Budapest (Hungary), Vienna (Austria), and Zurich (Switzerland) (Figure 2). The analyses explored the key factors influencing urban planning and city council policies, and formulated recommendations to introduce the concept and implementation of NBS at the local urban level. A scoping review (Peters *et al.*, 2015) was conducted between May and June 2023 using the Web of Science database. From a first search, it resulted in 924 outputs using the queries: "nature-based solutions" AND "urban-planning" between 2003–2023, in titles, abstracts or keywords of both scientific journals and books. Based on this previous search, and narrowing the manuscripts according to the interviews' content and codes, a final shortlist of twenty studies was defined.

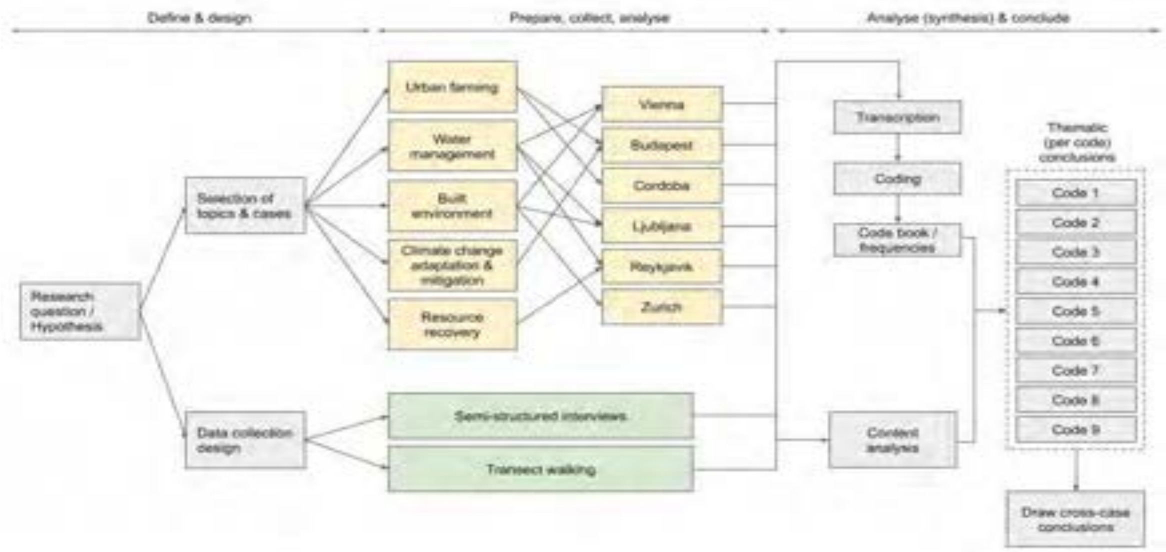

Figure 2. Multiple case study design (adapted from Yin, 2014).

The research followed an exploratory multiple case studies approach (Yin, 2014) (Figure 2). Exploratory studies in the field of urban planning and public policy offer important insights into issues that are still poorly covered in the literature and by policy makers (Wolfram, 2018). The multiple case studies approach (Hunziker *et al.*, 2021) involves the in-depth analysis of several individual cases. Data collection was conducted between August–September 2021 through semi-structured interviews designed to explore five main topics: (i) water management (Oral *et al.*, 2021); (ii) resource recovery (van Hullebusch *et al.*, 2021); (iii) urban agriculture (Canet-Martí *et al.*, 2021); (iv) built environment (Pearlmutter *et al.*, 2021); and (v) climate change adaptation and mitigation. Semi-structured interviews had a common structure designed to be effective across all cases and topics. The number of conducted interviews varied from 5 (Zürich) to 24 (Budapest), with an average of 12 interviewees/city; depending on the duration of the research mission at each city, and the availability of the stakeholders. Interviews were recorded and transcribed. A semi-open coded method including a total of 70 codes was used to analyse them. The coding method was developed by the research team and was based on the identification of common codes in order to analyse the wording of the collected interviews.

Results and Discussion

A total of 76 interviews with municipal managers and officials, academic experts, heads of citizens' associations and representatives of private companies from the six cities were conducted. As NBS encompasses a broad array of solutions, based on different natural processes, this variety led urban actors to have different perceptions about how to define and categorise NBS units and interventions. The constellation of different perceptions plays a key-role in providing a solid and comprehensive definition of NBS. Hence, our research study considers a broad spectrum of urban stakeholders. In Budapest and Ljubljana, experts and academics from research institutes and universities represented the most involved category. Their theoretical knowledge provided inputs in understanding the characteristics, potential, and technical limitations of NBS, and thus created opportunities to fill the knowledge gap about NBS. In Vienna, the snowball strategy led to the selection of some business representatives. Their views enabled understanding how sustainable NBS are in the market and how they can be an attractive field of investment for private actors. In Córdoba and Zurich, the selection process resulted in contacting mainly municipal officials and managers. The insights of local government representatives were relevant for understanding how NBS fit into broader policy strategies geared toward mitigating climate change and fostering urban regeneration. Civil society was extensively engaged in Budapest, Vienna and Reykjavik. Relative to these cities, the gaze of leaders of territorial associations, grassroots, citizen committees, and environmental associations offered important insights into how NBS are perceived by citizens and how they can respond to the real needs of local communities; it also fosters the adoption of NBS practices. Some specific results will be presented.

Conclusions

This research study analyses the main challenges and benefits derived from the implementation of NBS in six European cities by conducting semi-open interviews with different stakeholder groups on several thematic categories: water management, resource recovery, urban farming, climate change adaptation and mitigation, and built environment. The case study showed that the topic is present in the different European cities, although the understanding of the concept is quite diverse; consequently, the needs why different actors are interested to implement NBS, and the perceived barriers to actually use NBS are also manifold. Our presentation aims at describing the synergies and possible cooperations deriving from this scene.

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References:

Atanasova, N., Castellar, J.A.C., Pineda-Martos, R., Nika, C.E., Katsou, E., Istenič, D., Pucher, B., Andreucci, M.B., Langergraber, G., 2021. Nature-Based Solutions and Circularity in Cities. Circular Economy and Sustainability 1, 319–332, https://doi.org/10.1007/s43615-021-00024-1

Canet-Martí, A., Pineda-Martos, R., Junge, R., Bohn, K., Paço, T.A., Delgado, C., Alenčikienė, G., Skar, S.L.G., Baganz, G.F.M., 2021. Nature-Based Solutions for Agriculture in Circular Cities: Challenges, Gaps, and Opportunities. Water 13 (18), 2565, https://doi.org/10.3390/w13182565.

Hunziker, S., Blankenagel, M., 2021. Multiple Case Research Design. In: Research Design in Business and Management: A Practical Guide for Students and Researchers, 171–186. Springer Gabler, Wiesbaden, https://doi.org/10.1007/978-3-658-34357-6_9

Kabisch, N., Frantzeskaki, N., Pauleit, S., Naumann, S., Davis, M., Artmann, M., Haase, D., Knapp, S., Korn, H., Stadler, J., Zaunberger, K., Bonn, A., 2016. Nature-based Solutions to Climate Change Mitigation and Adaptation in Urban Areas: Perspectives on Indicators, Knowledge Gaps, Barriers, and Opportunities for Action. Ecology and Society 21 (2), 1–15, https://www.jstor.org/stable/26270403

Langergraber, G., Castellar, J.A.C., Pucher, B., Baganz, G.F.M., Milosevic, D., Andreucci, M.-B., Kearney, K., Pineda-Martos, R., Atanasova, N., 2021a. A Framework for Addressing Circularity Challenges in Cities with Nature-Based Solutions. Water 13 (17), 2355, https://doi.org/10.3390/w13172355.

Langergraber, G., Castellar, J.A.C., Andersen, T.R., Andreucci, M.-B., Baganz, G.F.M., Buttiglieri, G., Canet-Martí, A., Carvalho, P.N., Finger, D.C., Griessler Bulc, T., Junge, R., Megyesi B., Milošević, D., Oral, H.V., Pearlmutter, D., Pineda-Martos, R., Pucher, B., van Hullebusch, E.D., Atanasova, N., 2021b. Towards a Cross-Sectoral View of Nature-Based Solutions for Enabling Circular Cities. Water 13 (17), 2352, https://doi.org/10.3390/w13172352.

Nika, C.-E., Expósito, A., Kisser, J., Bertino, G., Oral, H.V., Dehghanian, K., Vasilaki, V., Iacovidou, E., Fatone, F., Atanasova, N., Katsou, E., 2021. Validating Circular Performance Indicators: The Interface between Circular Economy and Stakeholders. Water 13 (16), 2198, https://doi.org/10.3390/w13162198.

Oral, H.V., Radinja, M., Rizzo, A., Kearney, K., Andersen, T.R., Krzeminski, P., Buttiglieri, G., Ayral-Cinar, D., Comas, J., Gajewska, M., Hartl, M., Finger, D.C., Kazak, J.K., Mattila, H., Vieira, P., Piro, P., Palermo, S.A., Turco, M., Pirouz, B., Stefanakis, A., Regelsberger, M., Ursino, N., Carvalho, P.N., 2021. Management of Urban Waters with Nature-Based Solutions in Circular Cities – Exemplified through Seven Urban Circularity Challenges. Water 13 (23), 3334, https://doi.org/10.3390/w13233334.

Pearlmutter, D., Pucher, B., Calheiros, C.S.C., Hoffmann, K.A., Aicher, A., Pinho, P., Stracqualursi, A., Korolova, A.; Pobric, A., Galvão, A., Tokuç, A., Bas, B., Theochari, D., Milosevic, D., Giancola E., Bertino G., Castellar, J.A.C., Flaszynska, J., Onur, M., Garcia Mateo, M.C., Andreucci, M.B., Milousi, M., Fonseca, M., Di Lonardo, S., Gezik. V., Pitha, U., Nehls, T., 2021. Closing Water Cycles in the Built Environment through Nature-Based Solutions: The Contribution of Vertical Greening Systems and Green Roofs. Water 13 (16), 2165, https://doi.org/10.3390/w13162165.

Peters, M.D.J., Godfrey, C.M., Khalil, H., Mclnerney, P., Parker, D., Soares, C.B., 2015. Guidance for Conducting Systematic Scoping Reviews. International Journal of Evidence-Based Healthcare 13 (3), 141–146, https://doi.org/10.1097/XEB.0000000000000050

Raymond, C.M., Frantzeskaki, N., Kabisch, N., Berry, P., Breil, M., Nita, M.R., Geneletti, D., Calfapietra, C., 2017. A Framework for Assessing and Implementing the Co-benefits of Nature-Based Solutions in Urban Areas. Environmental Science & Policy 77, 15–24, https://doi.org/10.1016/j.envsci.2017.07.008

van Hullebusch, E.D., Bani, A., Carvalho, M., Cetecioglu, Z., De Gusseme, B., Di Lonardo, S., Djolic, M., van Eekert, M., Griessler Bulc, T., Haznedaroglu, B.Z., Istenič, D., Kisser, J., Krzeminski, P., Melita, S., Pavlova, D., Płaza, E., Schoenborn, A., Thomas, G., Vaccari, M., Wirth, M., Hartl, M., Zeeman, G., 2021. Nature-Based Units as Building Blocks for Resource Recovery Systems in Cities. Water 13 (22), 3153, https://doi.org/10.3390/w13223153.

Wolfram, M., 2018. Cities Shaping Grassroots Niches for Sustainability Transitions: Conceptual Reflections and an Exploratory Case Study. Journal of Cleaner Production 173, 11–23, https://doi.org/10.1016/j.jclepro.2016.08.044

Yin, R.K., 2014. Case Study Research Design and Methods, fifth ed. Thousand Oaks, Sage, CA.

The use of Participatory System Dynamics Modelling to support 'Nexus doing': preliminary results from the Koiliaris (Greece) case study

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ABSTRACT

Nexus thinking was first conceived at the WEF (2011) and found a significant development in the recent literature (e.g. Gai et al. 2022, Herrera-Franco et al. 2023). The essence of the Nexus is about the interconnections between different sectors (e.g. water, energy, food, ecosystems) and is also inextricably connected to the concept of resources security, under increasing pressures and vulnerabilities. Nexus thinking advocates that water, energy, ecosystems and food systems should be viewed collectively and holistically in order to reach water, energy and food (WEF) security (WEF, 2011).

Addressing such complexity requires a clear understanding of system structure and of mutual interactions between sub-systems which have been, to date, largely considered in isolation from each other. System Dynamics Modelling (SDM) can describe the assumed/perceived underlying (material, informational, social etc) structure of real-world systems. SDM includes a series of tools and methods to describe, model, simulate and analyse dynamically complex issues and/or systems, taking jointly into account the processes, information, organizational boundaries and strategies. It comprises a set of conceptual tools that enable the understanding of the structure and dynamics of complex systems as well as rigorous modelling methods for building formal computer simulations of complex systems and using them to design effective strategies (Sterman 2000). SDM techniques have been increasingly used in Nexus studies (e.g. de Vito et al. 2017; Laspidou et al. 2020; Sušnik et al. 2021), particularly supporting policy design and analysis, as they allow the integration of knowledge across domains and facilitate the participation of stakeholders.

The purpose of the present work is to show how the use of Participatory System Dynamics Modelling (PSDM) techniques can support Nexus thinking in a complex watershed in the Mediterranean area. In particular, the purpose is to show how it can be used to include stakeholder knowledge, and to develop an analysis of the key challenges of the study area and for the identification of leverage points that can be used to design potential measures that can support sustainability transitions.

Different approaches exist in SDM, whose use depends on analysis objectives, employed methodology and addressed audience. Causal Loop Diagrams (CLDs) provide a graphical representation of the system under investigation, focusing on the relationships among different variables. The direction of the connections between such variables defines the causal dependency, being positive (+) if the variables change in the same direction (i.e. they both increase or decrease) or negative (-) if they change in the opposite direction (Sterman 2000). Combinations of positive and negative causal relationships can form either reinforcing ('R') and balancing ('B') feedback loops. Reinforcing loops represent growing or declining actions, while balancing loops represent a mechanism of self-correction that contrasts and opposes change, and their analysis is crucial to describe the expected dynamic evolution of variables.

A methodological approach based on the use of PSDM techniques has been proposed in the LENSES project. It is based on the use of a holistic approach to system analysis which helps overcoming 'silo-thinking' (i.e. the sectoral fragmentation), highlighting the high interconnectedness among sectors (water-energy-food-ecosystems) and among the multiple agents involved in/impacted by Nexus resources management. Besides supporting the Nexus thinking phase, PSDM should help "Nexus doing" by finding barriers and leverage points within the system structure where nexus policies - that have the potential to change the problematic trend to a more desirable one – should be implemented.

The proposed approach has been broadly divided into two phases (i.e. 'qualitative' modelling, aiming at the definition of CLDs and 'quantitative' modelling, aiming at building stock and flow models). It has been

structured as a sequence of 'desk' and 'participatory' activities, that are briefly summarised in the following Table 1, with specific reference to the 'qualitative' modelling phase only.

Table 1. Overview of the methodological approach

Step	Description and Objectives	Outcome
1 (Desk)	Provide a basic understanding of each pilot area, based on **background information** (review of previous studies, projects, model results, etc.).	'Baseline' version of the CLD
2 (Participatory)	**Bilateral meetings** with pilot leaders to discuss the main Nexus challenges and strategic objectives for the area, the main resources involved and key sectors. **Participatory exercises**: individual interviews and/or workshops/focus groups with stakeholders	Identification of central variables, indicators, interconnections and interdependencies
3 (Desk)	Provide an **improved understanding** of each pilot area, based on the information provided by stakeholders	Revised version of the CLD
4 (Desk + Participatory)	**Analysis** of the CLD structure (feedback loops + causes and uses trees) and computation of graph theory metrics. Discussion and critical analysis of the results for the **identification of measures/strategies**	Validated version of the CLD, to identify key variables and potential leverage points

The methodological approach proposed is being developed and implemented in several case studies within the project, yet with adaptations due to specific needs and interests. The present work mainly deals with the implementation in the Koiliaris River Basin (Crete, Greece). It is characterized by severely degraded soils due to heavy agricultural impacts, including grazing, for many centuries. It is also affected by the imminent threat of desertification due to climate change. The main uses are related to intensively grazed shrubland and pasture; olive, citrus groves, vines, and vegetables; and mixed forest. The drainage network consists mainly of a river and two ephemeral streams providing surface runoff, and a relevant role is played by karstic springs which merge with the rest of the streams to form the main segment of the Koiliaris River. Further details can be found e.g. in Lilli et al. (2020).

The following Figure 1 shows the CLD produced for the Koiliaris at the end of Step #3. It basically results from the integration of: i) baseline information obtained through the review of background information on the study area; ii) expert knowledge, provided by the pilot leaders (TUC Team) who have an extensive knowledge of the area due to measurements and modelling activities performed in the last decades; iii) stakeholder knowledge, elicited through two focus groups organized in the study area in October 2022, and particularly oriented to better understand the role of agricultural activities over the area. A detailed description of the whole structure of the CLD is out of the scope of the present work, but the Figure immediately suggests a high level of interconnectedness exists among all the WEFE Nexus sectors.

Going further into details, the CLD has been explored through the analysis of selected graph theory metrics. The degree centrality, in particular, is the simplest metric, expressing the number of connections an element has. In general, elements with high degree are the local connectors/hubs and can be used for the identification of the key challenges. Particular attention has been given to high-degree variables that have also multi-sectoral impacts/dependencies, as they can suggest Nexus challenges.

In this regard, the analysis of the high-degree centrality variables highlights the role of agricultural activities in the Koiliaris area as 'agricultural productivity' (degree 9) along with both 'agricultural profitability' and 'agricultural sustainability' (degree 5) are high-ranked. A relevant driver in the sector is the high level of 'land fragmentation', which increasingly contributes to the low economy of scale and the low level of profit of traditional products (such as citrus and olive oil) along with the lack of 'Farmers' training' which reflects also in the development of 'Unsustainable agricultural practices'. Agricultural activities in the area are not (currently) limited by water quantity, as it is relatively abundant yet poorly managed, but the 'Water demand for irrigation' is central in the analysis (degree 7). Competitive water uses between irrigation, tourism, and drinking can cause insufficient water supply in some areas and such conflict might be exacerbated in the near future due e.g. to climate change impacts. The main challenge for the water sector is indeed mainly related to 'Groundwater (GW) quality' (degree 8), which is rather poor on average as effect of the presence of both point and diffuse sources of pollution, and on increasing salinity issues in some areas. The low water quality for irrigation has also increasingly negative impacts on agricultural productivity. As far as the environment/ecosystems are concerned, the main challenge is related to the 'Soil degradation' (degree 7) and to the 'State of natural areas' (degree 6) which are directly or indirectly impacted by productive activities (intensive agriculture, livestock farming, urbanization, etc.).

Figure 1. Causal Loop Diagram developed for the Koiliaris case study

The leverage points represent potential points of intervention in the system – i.e. elements in the system in which the impacts of a small action could provoke larger impacts. In the proposed methodology, the identification of leverage points is based on: i) the analysis of the feedback loops in which the above-mentioned key challenges are incorporated; ii) the identification of elements having the potential for large-scale impacts on the system, based on the analysis of centrality measures .

The feedback loop represented in the following Figure 2 (a *reinforcing* loop) could be central for understanding system state and evolution as it involves three variables characterized by high centrality degree ('Agricultural productivity', 'Agricultural profitability' and 'Water demand for irrigation'). An increase in 'Water demand for irrigation' (due e.g. to the spread of irrigated agriculture) can cause a reduction of the 'Irrigation water budget', which is related to a reduction in 'Agricultural productivity'. This can drive a decrease of 'Agricultural profitability'. As lower profits can hamper the spread of innovation in agriculture, a reduction in the adoption of 'Innovative irrigation techniques' can occur. This will result in a reduction of 'Water demand for irrigation', with a potential cascading reduction of the 'irrigation water budget'. This could easily drive the system towards unsustainable conditions.

The identification of impacts that can have relevant impacts on the system has been performed coupling the analysis of key loops with graph theory metrics. In particular, closeness centrality identifies elements that can affect the rest of the network most easily and usually have high impact on what is happening across the network. Among the high-ranked variables in terms of closeness centrality, the role of 'Nature-based Solutions' could be crucial as they are directly related to an increase of 'Agricultural profitability' (which can have a favourable influence on the above loop), along with an increase of 'Farmer training' which can positively affect both 'Agricultural productivity' and 'Water demand for irrigation'. Similarly, the increase of 'Financial incentives' can exert a strong influence on the adoption of 'Innovative irrigation techniques'.

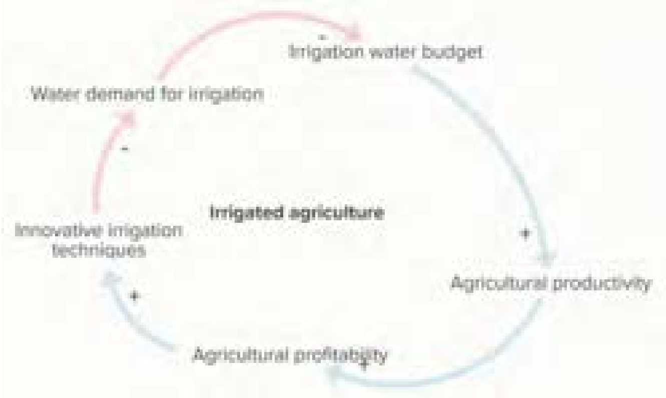

Figure 2. Focus on one of the key feedback loops in the CLD

The analysis above is a qualitative yet robust approach to 'Nexus thinking' and might help overcoming the gap towards 'Nexus doing'. PSDM techniques, and in particular CLDs, can help building in a participatory way a structured view of complex Nexus systems without losing scientific information. The analysis of the structure of the CLD (mainly based on graph theory metrics and the description/analysis of key feedback loops) can help identify the main Nexus challenges for a study area and as well as potential points of interventions on the systems as well as screening potential measures/actions. An additional step is needed towards 'Nexus doing', which could be covered by the development of quantitative (i.e. stock and flow) PSDM. A stock and flow model is currently being developed for the study area, and will integrate in a quantitative way information and data coming from models and/or measurements. It will be used for testing and comparing different potential scenarios for the system under investigation ultimately describing the impact of potential strategies on Nexus management.

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References:

de Vito, R., Portoghese, I., Pagano, A., Fratino, U., Vurro, M., 2017. An index-based approach for the sustainability assessment of irrigation practice based on the water-energy-food nexus framework. Advances in Water Resources, 110, 423–436. https://doi.org/10.1016/j.advwatres.2017.10.027

Gai, D. H. B., Shittu, E., Ethan Yang, Y. C., Li, H.-Y., 2022. A Comprehensive Review of the Nexus of Food, Energy, and Water Systems: What the Models Tell Us. Journal of Water Resources Planning and Management, 148(6). https://doi.org/10.1061/(ASCE)WR.1943-5452.0001564

Herrera-Franco, G., Bollmann, H. A., Pasqual Lofhagen, J. C., Bravo-Montero, Lady, Carrión-Mero, P., 2023. Approach on water-energy-food (WEF) nexus and climate change: A tool in decision-making processes. Environmental Development, 46, 100858. https://doi.org/10.1016/j.envdev.2023.100858

Laspidou, C. S., Mellios, N. K., Spyropoulou, A. E., Kofinas, D. T., Papadopoulou, M. P., 2020. Systems thinking on the resource nexus: Modeling and visualisation tools to identify critical interlinkages for resilient and sustainable societies and institutions. Science of The Total Environment, 717, 137264. https://doi.org/10.1016/J.SCITOTENV.2020.137264

Lilli, M. A., Nerantzaki, S. D., Riziotis, C., Kotronakis, M., Efstathiou, D., Kontakos, D., Lymberakis, P., Avramakis, M., Tsakirakis, A., Protopapadakis, K., Nikolaidis, N. P., 2020. Vision-Based Decision-Making Methodology for Riparian Forest Restoration and Flood Protection Using Nature-Based Solutions. Sustainability, 12(8), 3305. https://doi.org/10.3390/su12083305

Sterman, J., 2000. Business Dynamics: Systems Thinking and Modelling for a Complex World. McGraw-Hill Higher Education

Sušnik, J., Masia, S., Indriksone, D., Brēmere, I., & Vamvakeridou-Lydroudia, L. (2021). System dynamics modelling to explore the impacts of policies on the water-energy-food-land-climate nexus in Latvia. Science of the Total Environment, 775. https://doi.org/10.1016/j.scitotenv.2021.145827

WEF, 2011. Water security: the water–food–energy–climate nexus. Washington DC: World Economic Forum

Multi-criteria tool for Nature-based Solutions and Bioeconomy practices selection towards WEFE Nexus implementation: the case of Tinos Island

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Keywords: nature-based solutions, bioeconomy, WEFE nexus, multi-criteria assessment, tool, participatory workshop

ABSTRACT
During the last decades, the Mediterranean region has faced increased environmental challenges related to climate change and increased urbanization. The implementation of Nature-based Solutions (NBS) and Bioeconomy (BES) has become central in addressing these challenges through innovative actions. BES and NBS are related concepts, but they have distinct applications, objectives and priorities. NBS prioritize the conservation and restoration of natural systems as well as the creation of novel ecosystems to address societal and environmental challenges (Almenar et al., 2021), while BES focus on using biological resources to create economic value and reduce environmental impact (D'Amato and Korhonen, 2021).

The SureNexus project aims to assess, validate, quantify, and demonstrate the application of alternative engineering solutions for Nexus implementation (NBS and BES) focusing on the conservation and restoration of ecosystem services and biodiversity, as well as the reuse of waste by-products from agriculture or the recovery of nutrients from reclaimed water. Within the framework of the project, a NBS/BES selection tool was developed with the aim to identify and prioritize solutions that cover the four elements of the WEFE Nexus (water energy, food, ecosystems) and have considerable impact in terms of socio economic parameters (Carmona-Moreno et al., 2019; Carvalho et al., 2022). It is a multi-stakeholder participatory tool, designed to be used by stakeholders and experts during workshops organized at the four (4) Demo Sites (DS) across the Mediterranean region in Greece, Spain, Morocco, and Israel) and online.

The SureNexus tool development took place in three distinct phases by using a Multi-Criteria Assessment (MCA) methodology (Jiménez-Ariza et al., 2023; Namani et al., 2021). During the first phase, the main criteria and available solutions of the MCA tool were defined with the aim to ensure the broadest WEFE nexus coverage, as well as the highest WEFE nexus impact achieved by the solutions. The following eight (8) criteria were defined: Water, Energy, Food, Ecosystems, Social, Economic, Climate Change and Institutional (Dumitru, A. and Wendling, 2021). Each criterion included a list of sub-criteria, to be used by the stakeholders for the assessment of the solutions. Furthermore, extensive NBS and BES lists were assembled by the SureNexus partners, and their relevance to the WEFE nexus was specified. During the second phase, the tool was customized for each DS. The general list of solutions was refined through consultations with the DS leaders, so that it can be applicable to their local context. Moreover, the list of sub-criteria was reviewed and adapted to each DS, while weights were attributed to each of the eight criteria. The third and final phase regards the application of the MCA tool at each DS through participatory workshops with the stakeholders. Additional workshops will also take place online, in order to involve experts and higher-level stakeholders in the process. So far, the SureNexus tool has already been used in the first DS workshop, that took place at the Greek DS.

The Greek DS is located on Tinos Island in the Aegean Sea. Tinos was chosen as a DS because of its specific characteristics such as the increasing alternative tourism, hiking and ecotourism. The development of tourism on the island has led to a large demand for water and energy during high season and several problems regarding waste and wastewater management (no sewage treatment plant). The DS includes two (2) pilots that explore solutions to the aforementioned challenges through NBS and BES: i) a solar driven desalination unit for the production of fresh water and edible salt, combined with a greenhouse where tropical plants are

grown (Agios Fokas pilot) and ii) an off-the-grid ecofriendly tourist facility operating on the principles of sustainability, autonomy and circularity (Potamia pilot). Throughout the SureNexus project, the two (2) pilots aim to expand and optimize their systems through alternative, nature-based, low-cost solutions for the treatment and recovery of valuable resources.

The workshop, was organized under the theme "A Sustainable Future for the Mediterranean" and was guided by the following question: How could future tourism, NBS and agricultural production work together on Tinos Island? Its duration was seven (7) hours, and it comprised of two (2) parts. During the first part, the local stakeholders reviewed the main uncertainties and enabling factors associated with the WEFE Nexus implementation at a Mediterranean level and then identified the enabling factors and barriers at the local level. This activity, which was implemented partly individually and partly in small focus groups, functioned as an icebreaker between the workshop participants, and as an introductory session to prepare for a solid understanding of the challenges and strengths of Tinos Island, before proceeding to the suggestion of specific solutions. The second part focused on the implementation of the SureNexus NBS/BES tool, where the stakeholders prioritized a predetermined number of solutions from the lists as the most promising and relevant solutions for implementation for each pilot. The final selection of NBS/BES was based on the rating of the solutions against sub-criteria, which correspond to the main eight (8) criteria of the MCA tool.

The tool version of the Agios Fokas solar desalination pilot included 18 available solutions, and 40 sub-criteria. The tool of the Potamia pilot eco-touristic facility pilot included 11 available solutions and 34 sub-criteria. The weights of the eight (8) criteria for each pilot is presented in Table 1.

Table 1: The weights of the eight criteria for each pilot of SureNexus Demo Site 2 on Tinos Island.

		Pilot 1 (Agios Fokas)	Pilot 2 (Potamia)
WEFE criteria	Water	31.25	12.5
	Energy	12.5	6.25
	Food	12.5	12.5
	Ecosystems	18.75	18.75
Impact criteria	Social	6.25	25
	Economic	6.25	6.25
	Climate Change	6.25	12.5
	Institutional	6.25	6.25

The workshop results indicated that for the Agios Fokas Pilot Plant, the stakeholders identified the main challenge as low freshwater production. They almost unanimously proposed as a solution the implementation of an alternative water source, i.e. rainwater harvesting on the roof of the greenhouse and storage of the harvested water (Figure 1). The second-best solution was the creation of vegetable gardens to increase local production. Regarding the Potamia tourist facility, decentralised composting was voted as the best solution (Figure 2) as a means to manage the organic based waste produced during the high season by the influx of tourists. The second best rated solution was residential water harvesting, which is indicative of the pressure that water scarcity creates on the island.

The methodology and tool presented in this work can be adapted for implementation in different contexts that face WEFE nexus related challenges. The next step is to apply the developed tool at the other three DS of the project, each of which represents a unique context: constructed wetlands for winery wastewater treatment through cork granules (Spain), smart citrus trees orchard (Morocco), agrovoltaics vegetable farming (Israel). Additional workshops will take place online, to consider the perspective of the Mediterranean at the regional level.

The MCA methodology is a decision-making tool used to evaluate and compare options or alternatives based on multiple criteria or factors. While MCA has its advantages, it also comes with some limitations (Mendoza and Prabhu, 2000; Triantafyllou, 2000; Ruangpan et al. 2021). Its advantages include the following characteristics: comprehensive evaluation, transparency and objectivity, consideration of diverse perspectives, flexibility and customization, sensitivity analysis. However, the criticism on the MCA methodology may stem from the following characteristics: complexity, subjectivity in criteria weighting: limited accuracy, difficulty in comparing different dimensions, lack of consideration for interactions.

Considering the aforementioned characteristics of MCA, its application in the context of WEFE nexus provides opportunities for operationalizing a complex concept and comparing innovative solutions that stakeholders may not be very familiar with. The application of the SureNexus tool, especially in a multi-stakeholder environment, can enable further analysis and discussion based on the MCA results, ensuring a participatory and empowering transition towards climate change adaptation and sustainable development, based on NBS and BES.

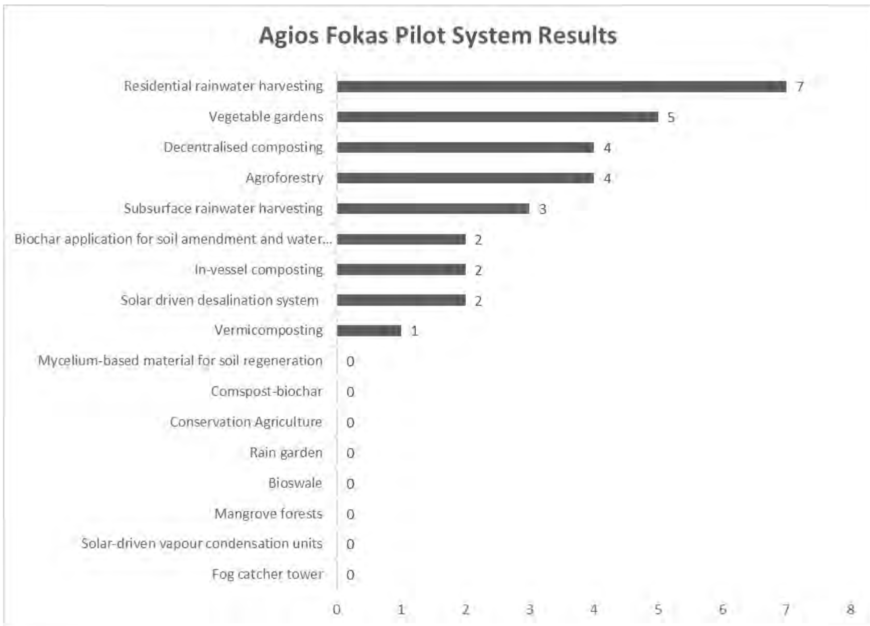

Figure 1: Prioritised solutions for the Agios Fokas pilot.

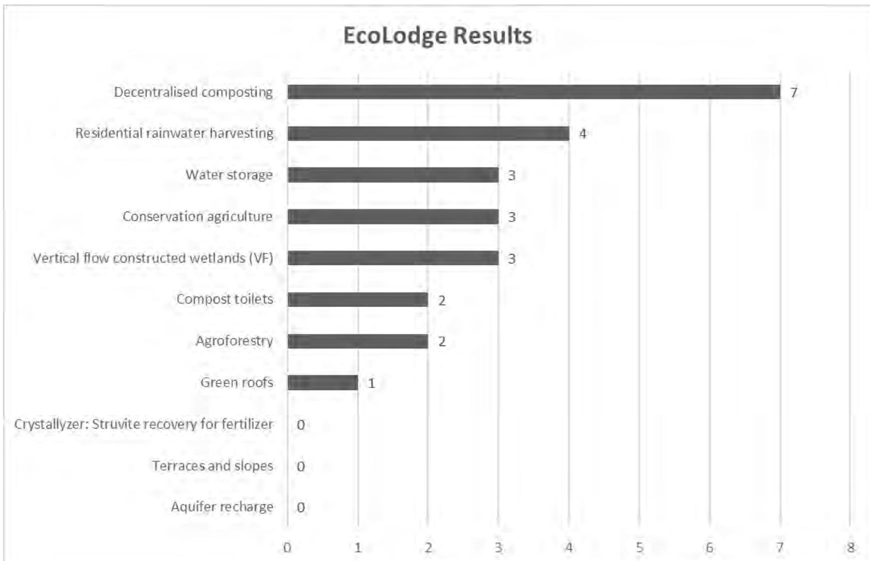

Figure 2: Prioritised solutions for the Potamia pilot.

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References

Almenar, J.B., Elliot, T., Rugani, B., Philippe, B., Gutierrez, T.N., Sonnemann, G. and Geneletti, D., 2021. Nexus between nature-based solutions, ecosystem services and urban challenges. *Land use policy*, *100*, p.104898.

Carmona-Moreno, C., Dondeynaz, C. and Biedler, M. eds., 2019. *Position Paper on Water, Energy, Food and Ecosystems (WEFE) Nexus and Sustainable Development Goals (SDGs)*. Publications Office of the European Union.

Carvalho, P.N., Finger, D.C., Masi, F., Cipolletta, G., Oral, H.V., Toth, A., Regelsberger, M. and Exposito, A., 2022. Nature-based solutions addressing the water-energy-food nexus: Review of theoretical concepts and urban case studies. *Journal of Cleaner Production*, *338*, p.130652.

D'amato, D. and Korhonen, J., 2021. Integrating the green economy, circular economy and bioeconomy in a strategic sustainability framework. *Ecological Economics*, *188*, p.107143.

Dumitru, A. and Wendling, L., 2021. *Evaluating the impact of nature-based solutions: A handbook for practitioners*. European Commission EC.

Jiménez-Ariza, S.L., Rey, C.V., Rodríguez, J.P. and Guzmán-Ramírez, M., 2023. Multi-Criteria Decision Analysis Inputs for Planning the Implementation of Nature-based Solutions in Urban Contexts. *ACE: Architecture, City and Environment*, *18*(52).

Mendoza, G.A. and Prabhu, R., 2000. Multiple criteria decision-making approaches to assessing forest sustainability using criteria and indicators: a case study. *Forest ecology and management*, *131*(1-3), pp.107-126.

Namany, S., Govindan, R., Di Martino, M., Pistikopoulos, E.N., Linke, P., Avraamidou, S. and Al-Ansari, T., 2021. An energy-water-food nexus-based decision-making framework to guide national priorities in Qatar. *Sustainable Cities and Society*, *75*, p.103342.

Ruangpan, L., Vojinovic, Z., Plavšić, J., Doong, D.J., Bahlmann, T., Alves, A., Tseng, L.H., Randelović, A., Todorović, A., Kocic, Z. and Beljinac, V., 2021. Incorporating stakeholders' preferences into a multi-criteria framework for planning large-scale Nature-Based Solutions. *Ambio*, *50*, pp.1514-1531.

Triantaphyllou, E. and Triantaphyllou, E., 2000. *Multi-criteria decision-making methods* (pp. 5-21). Springer US.

Tiganokinisi: Social Innovation though the Collection and Recycling of Domestic Used Cooking Oil in Cyprus

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Keywords: social innovation, environment, biofuel

ABSTRACT

The inappropriate disposal of millions of tons of domestically produced used cooking oil (UCO), either down domestic household drains or in landfill, causes significant detrimental effects on the environment but also constitutes the loss of a valuable resource, since used cooking oil is a sought-after feedstock for biodiesel production. This paper presents findings from Tiganokinisi, a social innovation solution and a circular economy practice implemented in Cyprus. Tiganokinisi collects domestic used cooking oil (dUCO) through schools, the dUCO is sold to the refineries to become biodiesel and the proceeds from the sale return to the schools to be invested in environmental education activities, green infrastructure, laboratories, technology innovation and more. At the same time young universities graduates are trained as interns and local communities are involved and support. This is the disruptive, innovation and social framework of Tiganokinisi which led to a number of international awards and recognitions. To date, over 470,000 Euros have been distributed to Cypriot schools and over 800 actions have been implemented with this money. The next step is the exploitation and replication of Tiganokinisi as a worldwide best practice and social innovation that maximizes the environmental and social impacts of dUCO management.

1. Introduction

Used cooking oil (UCO), is edible oil of vegetable or animal origin that has been used to cook food to a point where it is no longer fit for that purpose. There are two main sources of UCO: Commercial UCO from hotels, restaurants and caterers (HORECA) and domestic UCO (dUCO) from households. It is estimated that at least 60 million tons of UCO are produced annually among the largest producing countries i.e., China, Malaysia, the USA, Europe, Korea, India, Indonesia, Canada, and Japan [1], [2]. It is also reported that more than 60% of UCO generated globally is improperly disposed of [3] ending up in the environment, either through direct disposal in drains or through bottling and disposal in landfills. UCO disposed down the drains costs millions of euros to water boards for pipe cleaning and maintenance of sewers from frequent fatbergs blockages [e.g., 4] and for managing Fat Oil and Grease in wastewater treatment plants. Several developments have caused a rapid growth in the UCO market. In Europe, two European Directives, the Renewable Energy Directive [5] and the Fuel Quality Directive [6], aiming to promote the use of renewable sources of energy, have led to an increased demand for UCO as feedstock for biodiesel production. All around the world the collection of commercial UCO is much more developed and practiced than collection from households. This is mainly because UCO collection from households requires advanced and well-organized collection systems and depend on individuals' willingness to participate [7]. For example, in Europe only 5.6% of dUCO is collected compared to 85% from commercial sources [8], in India dUCO collection ranges from 0%-1%, in Japan 3-5%, and in Malaysia 12-20% [2]. Research has shown that domestic used cooking oil produces biodiesel with a higher yield than commercial UCO [9]. There are, therefore, significant environmental and economic reasons for diverting dUCO from inappropriate disposal where it can be used to produce biodiesel, thus facilitating the transition to a circular bioeconomy. This paper presents results from the 10 years of implementation of Tiganokinisi in Cyprus, a social reverse logistics system for collecting and recycling domestic UCO through schools [10]. Tiganokinisi covers approximately the 4% of local dUCO collection. The social innovation of Tiganokinisi derives from the return of the proceeds from the sale of the collected dUCO to schools to be invested in ongoing environmental education and green infrastructure and technology within the participating schools.

2. Method

2.1. Setting Up Tiganokinisi in Cyprus

Tiganokinisi which in Greek means "Frying pan movement", has been initiated, developed and operated by the NGO AKTI Project and Research Centre. The initiative was implemented as a pilot in five schools during the school year 2012–2013 in collaboration with the Pedagogic Institute of the Cypriot Ministry of Education and Culture. Following the success of the pilot phase 'Tiganokinisi', was expanded to include today 475 schools, corresponding to approximately 98% of schools in Cyprus (primary, secondary, and technical education).The novelty of Tiganokinisi is the close link between environmental education and the provision of funds to schools through the sale of the collected UCO. Each school receives an amount equivalent to approximately 500–600 Euros for each ton of UCO collected, to be invested in green infrastructure and technology, with a view to furthering environmental education and promoting technological innovation.
Tiganokinisi is implemented as follows:

1. Oil collection drum installation: Interested schools contact the NGO AKTI and an oil collection drum is installed at the school. Students take dUCO from home and deposit it in the drum. Once the drum is full, the school contacts the program, a driver is dispatched to the school, and the oil is collected and transported to a management facility and from there to a biodiesel refinery.
2. Community involvement: Local businesses donate their UCO to local schools and local authorities facilitate collection from less accessible households.
3. Educational presentations: Schools are visited by Tiganokinisi's mobile information and education center that provides hands-on, sustainability education through several experimental setups (e.g transformation of UCO into biodiesel, resources saving, organic waste management).
4. Digital platform: Schools have access to a digital platform through which they can identify sustainable technologies to invest in using Tiganokinisi's funds.
5. Experiential education: An educational guide is available, allowing teachers to use the program as an educational tool in their classroom. The guide is continuously updated to include any new technologies/infrastructure installed at the schools and provides details on how to incorporate them to become an essential part of teaching.

2.2. Participation of Schools

Schools are encouraged to participate in the program through official circulars issued by the Pedagogic Institute of Cyprus. The involvement of schools in Tiganokinisi is therefore voluntary and interrelated to the willingness of the schools' management to take action for the implementation of the program.

2.3. Stakeholder Participation

The successful participation of schools in the program is primarily based on the collaboration of teachers, students, parents and the local community. Teachers encourage students to bring UCO from their homes; students are then engaging their parents in the process of collecting UCO at home. Schools are also encouraged to enhance their collection of UCO by working together with their local community.

2.4. Data Collection, Analysis, and Interpretation

AKTI's team records and registers the amount of UCO collected by each school and associated collection points (i.e., HORECA businesses). By the end of the school year, the cumulative quantities of UCO and corresponding funds for each school are calculated. Results are double-checked by the Pedagogical Institute and are announced to schools through an official circular. By the beginning of the next academic year, schools receive the funds that they accumulated through Tiganokinisi in the past year. They then provide a short report to the Pedagogic Institute about how they invest the money, linking the actions they implement to the 17 Sustainable Development Goals [10]. Data on the number of participating schools and businesses, on the amount of collected UCO and on the amount of money returned to schools undergo simple statistical analysis that allows the observation of trends. Information provided by schools on the investment of the received funds is analyzed and practices are categorised into four main groups: 'Greening of schools', 'Infrastructure and Technologies', 'Awareness Raising', and 'Educational Material'.

3. Results

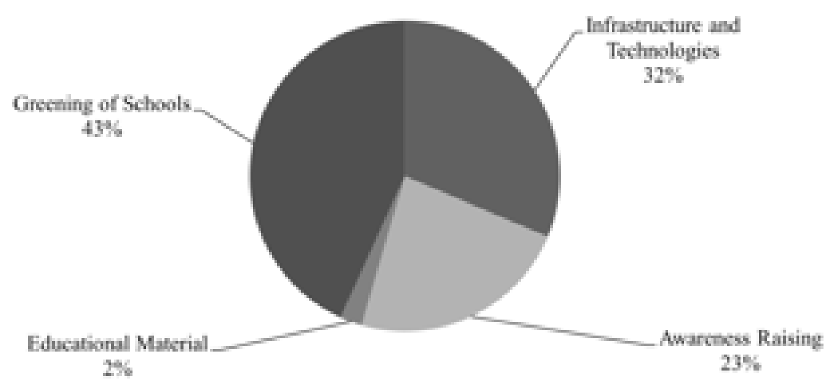
Within the 9 years of Tiganokinisi's nationwide implementation in Cyprus, there was a steady increase in the number of participating schools, reaching 475 schools in the 2021-2022 academic year. This growth has taken place with relatively little publicity, as a result of the positive experience of participating schools and the support of the Pedagogical Institute/Ministry of Education.

Table 1 Evolution of Tiganokinisi's implementation in Cyprus.

School Year	No. Participating Schools	UCO form Schools (kg)	No. of Active Businesses (kg)	UCO from Businesses (kg)	Total UCO Collected (kg)	Funds to Schools (€)
2014-2015	282	59885	63	11726	71611	37161
2015-2016	312	66296	65	14565	80861	50836
2016-2017	310	71105	59	16507	87612	53761
2017-2018	376	88933	95	24933	113866	66249
2018-2019	428	86043	117	35702	121745	67026
2019-2020	444	73199	124	37708	110907	65828
2020-2021	462	81058	130	45699	126757	67288
2021-2022	475	80021	143	57681	137702	68308

There is also a steady increase of the dUCO collected each year, apart from the school year 2019-2020, where the Covid-19 Pandemic had disrupted the normal operation of schools, therefore and dUCO collection. In the school year 2021-2022, a total of 80102 students became involved in Tiganokinisi through their school's participation and an average amount of 2 kg of dUCO per student was collected.. Since 2014, schools have received 476,457 Euros, which have been invested in the 'Greening of schools' (43% of all distributed funds), in the purchase and installation of green 'Infrastructure and Technologies' (32% of all distributed funds), on 'Awareness Raising' activities (23%), or in the purchase of 'Educational Material' (2%) (Figure 1). The category 'Greening of schools' includes the creation of botanic and herb gardens, of shaded areas, using trees and sheds made of sustainable materials. The category 'Infrastructure and Technologies' includes the purchase of recycling bins, composters/shredders, solar water heaters, hand driers, LED lights, water saving equipment, solar ovens, and other equipment. The purchase of environmentally related books, model wind turbines, solar vehicles, etc. is included in the 'Educational Material' category. The 'Awareness raising' includes awareness campaigns within schools (eg use reusable food and drink containers) and local community.

Figure 5 Modes of investment of Tiganokinisi's Funds by Schools



Discussion

Tiganokinisi meets a series of social and educational needs that determine its long-term impact and meet several United Nations Sustainable Development Goals (SDGs) [12]:

- SDG 4 Quality Education: It transforms school infrastructure through the provision of funds and helps further traditional and experiential education. It promotes inclusive and quality education as well as lifelong learning, through the involvement of the community.
- SDG12 Responsible consumption and production: It applies the waste hierarchy to an inappropriately managed waste. It ensures that natural resources are sustainably managed.
- SDG 13 Take urgent action to combat climate change and its impact: The implementation of practical solutions to real environmental and social problems allows children, and the society to become a part of the circular economy and contribute to the fight against climate change.

- SDG 17 Global partnership for sustainable development: It encourages effective public, public-private and civil society partnerships for effective dUCO collection.

For all these innovative and disruptive characteristics, Tiganokinisi has been shortlisted in 2015 in Elsevier's Green and Sustainable Chemistry Challenge as one of the 53 more powerful examples internationally, was recognized in 2020 by the European Commission as one of EU's best practices in Social Innovation, representing Cyprus, has been awarded in 2021 with an exemplifying quality certification in GENE Global education Award and has been presented by the Cypriot Minister of Education in his welcome speach during the Ninth Environment for Europe Ministerial Conference in October 2022 as a best practice for education on sustainability.

Conclusions

Tiganokinisi implements advanced and well-organized collection systems coupled with education activities and promotion of social innovation. These are important factors for a successful and innovative dUCO management scheme [7]. Tiganokinisi implementation in Cyprus is a flagship demonstration for its potential to become a worldwide best practice of circular economy, quality education and social innovation under the more "user-friendly" name InnovOleum.

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References:

1. Pelemo, J., Akindeji, K.T., Inambao, F.L., Awogbemi, O. and Onuh, E.I., 2022. A Comparative Evaluation of Biodiesel and Used Cooking Oil as Feedstock for HDRD Application: A Review. Diesel Engines and Biodiesel Engines Technologies, p.61.
2. Kristiana, T., Baldino, C. and Searle, S., 2022. An estimate of current collection and potential collection of used cooking oil from major Asian exporting countries. Work. Pap, 21.
3. Awogbemi, O., Onuh, E.I. and Inambao, F.L., 2019. Comparative study of properties and fatty acid composition of some neat vegetable oils and waste cooking oils. International Journal of Low-Carbon Technologies, 14(3), pp.417-425.`
4. Thames Water. Available online: https://www.thameswater.co.uk/about-us/newsroom/latest-news/2020/dec/help-keep-the-sewers-clear-at-christmas (accesed on 07 2023)
5. European Union. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (Text with EEA relevance). Off. J. Eur. Union 2009, 140, 16–62.
6. European Union. Directive 2009/30/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 98/70/EC as regards the specification of petrol, diesel and gas-oil and introducing a mechanism to monitor and reduce greenhouse gas emissions and amending Council Directive 1999/32/EC as regards the specification of fuel used by inland waterway vessels and repealing Directive 93/12/EEC (Text with EEA relevance). Off. J. Eur. Union 2009, 140, 88–113.
7. Greenea. Available online: https://www.greenea.com/wp-content/uploads/2017/03/Greenea-article-UCO-household-collection-2017.pdf (acessed on 21 July 2023)
8. Greenea. Available online: https://www.theicct.org/sites/default/files/publications/Greenea%20Report%20Household%20UCO%20Collection%20in%20the%20EU_ICCT_20160629.pdf (accessed on 18 July 2023).
9. Li, H.L.; Yu, P.H. Conversion of waste cooking oil into environmentally friendly biodiesel. SpringerPlus 2015, 4 (Suppl. 2), P7.
10. Loizides, M.I., Loizidou, X.I., Orthodoxou, D.L. and Petsa, D., 2019. Circular bioeconomy in action: collection and recycling of domestic used cooking oil through a social, reverse logistics system. Recycling, 4(2), p.16.
11. Dos Santos Ferreira, L.; da Silva César, A.; Conejero, M.A.; da Silva Guabiroba, R.C. A voluntary delivery point in reverse supply chain for waste cooking oil: An action plan for participation of a public-school in the State of Rio de Janeiro, Brazil. Recycling 2018, 3, 48.
12. United Nations. Transforming Our World: The 2030 Agenda for Sustainable Development A/RES/70/1; UN: Nairobi, Kenya, 2015.

Combining Public Participation, Participatory Design and AI to Promote Integrated Planning Approaches

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Keywords: public participation, circular economy, natural language processing, participatory design

ABSTRACT

To date, Circular Economies have largely been driven by top-down national or trans-national legislation such as EU Circular Economy Package or Chinese Circular Economy Promotion. Bottom up or grass roots engagement have been minimal and innovation has been largely restricted to working within 3R or 4R frameworks to reduce, reuse, recycle materials and products or recover waste as energy. Greater implementation of CE's needs a paradigm shift in public attitudes coupled with greater innovation that moves from 3R to 9R framework and places greater attention to users needs and underlying cultural values that can motivate public preferences and actions. Building on insights obtained from an ethnographic study of the successful transition of two Scandinavian cities of Växjö and Sønderborg towards becoming fossil-fuel free economies, the presentation explores use of Natural Language Processing tools to create shared narratives and stories from large format public engagement that express common interests, values and priorities that in turn can contribute to a participatory design of CE's in terms of public policy, infrastructure planning and specific products and processes. The presentation uses published data from the City of Christchurch community wide engagement programme entitled 'Share an Idea' following the 2011 earthquakes.

Session A3: Resource recovery from water

Production and recovery of orthophosphate from phosphonate-contaminated wastewater combining ozonation and ultraviolet advanced oxidation processes

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Keywords: Advanced oxidation processes, ozonation, ultraviolet, phosphonate

ABSTRACT
Phosphonates, a group of contaminations of concern in wastewater significantly contribute to organic phosphorus pollution, especially when considering industrial wastewater. This work systematically studied the UV, O_3 and O_3/UV advanced oxidation processes in view of treating phosphonate-contaminated wastewater. In particular, the transformation of 1-hydroxyethane-1,1-diphosphonic acid (HEDP) to Ortho-P was investigated. Different operating parameters such as ozone dosage, pH and reaction time are optimized to maximize phosphonate removal efficiency. The results demonstrate that phosphonate could be almost completely converted to Ortho-P in the O_3/UV process after 90 minutes of reaction with 6 mg/ (min L_{water}) regardless of the pH change. Almost no Ortho-P (<5%) is produced during the UV process. In the single O_3 process, the pH value has a significant impact on the ortho-P production. Under neutral and alkaline conditions, the production efficiency of Ortho-P can reach 70% or higher which decreased to only 30% or less under acidic conditions. Probably, protons consume a significant amount of high-energy electrons under acidic conditions, which prevents the formation of reactive oxidizing species (ROS). The O_3/UV process is demonstrated as an effective method for the conversion of organic phosphorus to inorganic phosphorus, regardless of the pH of the waste water. Further research and optimization are recommended to explore the practical implementation, operational parameters, and cost-effectiveness of the O_3/UV process for organic phosphorus removal in real wastewater treatment applications.

Introduction

Phosphorus (P) is an essential nutrient that plays a vital role in plant growth. However, the excessive presence of phosphorus in water bodies has become a significant environmental concern and burden. The elevated levels of phosphorus in water bodies contribute to eutrophication, leading to harmful algal blooms, oxygen depletion, and degradation of aquatic ecosystems[1,2]. Efforts to manage phosphorus pollution involve implementing stringent regulations, promoting best management practices in agriculture, and improving wastewater treatment processes. Additionally, exploring innovative technologies for phosphorus removal and recovery from water bodies is crucial to mitigate the adverse impacts of phosphorus pollution and protect water quality.

Advanced oxidation processes (AOPs) have emerged as a promising solution for the treatment of phosphonates, which are persistent organic P containing pollutants. AOPs utilize powerful oxidative agents such as hydroxyl radicals to degrade and mineralize these compounds, effectively removing them from water sources. In recent years, significant progress has been made in the development of AOPs, including methods like photocatalysis[3–5], ozonation[6–8], and electrochemical oxidation[9,10]. These processes offer several advantages, such as high degradation efficiency, versatility in treating a wide range of phosphonates and the ability to target specific contaminants. Furthermore, AOPs can be easily integrated into existing water treatment systems, making them a practical and sustainable option for phosphonate removal. However, challenges still remain in terms of process optimization, cost-effectiveness, and the management of potentially harmful by-products. Continued research and innovation in AOPs are necessary to further enhance their efficiency and ensure their safe implementation for the treatment of phosphonates.

Among AOPs, ozonation has emerged as a promising technique for the treatment of organophosphorus compounds. This process involves the application of ozone, a strong oxidizing agent, to degrade and eliminate phosphonates compounds through oxidation reactions. The ozonation of organophosphorus compounds has been extensively studied and has shown significant potential for their removal. Ozone reacts with the organic functional groups present in these compounds, leading to the cleavage of phosphorus-carbon bonds and the formation of by-products that are less toxic or easier to remove. The efficiency of ozonation is influenced by various factors, including ozone dosage, pH, temperature, and contact time. Moreover, the presence of other water constituents, such as natural organic matter and inorganic ions, can affect the overall ozonation performance. In recent years, advancements in ozone generation technologies and process optimization strategies have improved the effectiveness of ozonation for organophosphorus compound removal. However, challenges remain, including the management of potentially harmful by-products and the need for cost-effective implementation on a large scale. Further research is required to explore the degradation mechanisms, optimize process conditions, and assess the environmental impact of ozonation for the treatment of organophosphorus compounds. The combination of ozonation with other technologies in water treatment presents a promising approach for enhanced contaminant removal and process efficiency. For example, the combination of ozone and UV irradiation synergistically enhances the degradation of contaminants, providing an efficient and rapid water treatment process. Overall, the integration of ozonation with various treatment methods demonstrates the potential to achieve advanced water purification, improved removal of contaminants of concern, and the production of high-quality water for diverse applications.

Materials and Methods

Reagents and Materials

1-Hydroxyethylidenebis (HEDP) was purchased from Thermo Scientific. Other reagents including sodium hydroxide (NaOH), boric acid (H_3BO_3) were purchased from Sigma-Aldrich (Belgium). Deionized (DI) water was used to prepare the work solution. Synthetic HEDP wastewater with an initial concentration of 100 mgP/L was prepared by spiking HEDP stock solution to DI water.

Experimental Setup and Procedures

The experiment setup is shown in Fig.1. A cylindrical glass column with a height of 100 cm and a gas diffusion chamber at the bottom of the column was used for the experiments (see the right part of Fig.1). The outer glass of the reactor is high borosilicate glass, which is resistant to ozone oxidation, and the inside is a quartz glass tube, which is used to install ultraviolet lamps. The reactor was performed out in a semi-batch mode with a fixed liquid volume of 3 L. An ozone generator (COM-AD-02, Anseros GmbH, Germany) was used to produce O_3 gas from pure O_2 gas. The ozone concentration at the inlet was set to 30 ± 1 mg/L. The ozone/oxygen gas mixture entered the reactor at a constant flow rate (0.6 L/min), resulting in an O_3 dose of 6 mg/ (min L_{water}). A gas analyzer (GM-OEM, Anseros GmbH, Germany) was used to measure the inlet and outlet O_3 concentration. A Cole-Parmer DAQ module (model FN-18200–00) was used to record the gas concentration once per second. Samples (20 mL) were collected for analysis at the desired sampling times and stored a refrigerator at 4°C before analysis. The O_3/UV experiment was performed in a manner similar to the single ozonation experiment. All experiments were performed at room temperature under atmospheric pressure (101 kPa) and in triplicate.

Analyses

The Ortho-P (P-PO_4^{3-}) and total phosphorus (TP) were determined according to standard methods using the commercial Hach test kits coupling with an ultraviolet-visible spectrophotometer (DR2800, Hach, Belgium). The pH was measured using portable pH meter (HQ30d, HACH, US). The Ortho-P production efficiency (R, %) can be calculated as follows:

$R = c_t/c_0 * 100$ (1)

where c_t and c_0 represent the concentration of Ortho-P in the treated HEDP samples and that of Total-P in the initial HEDP samples (100 mg/L), respectively.

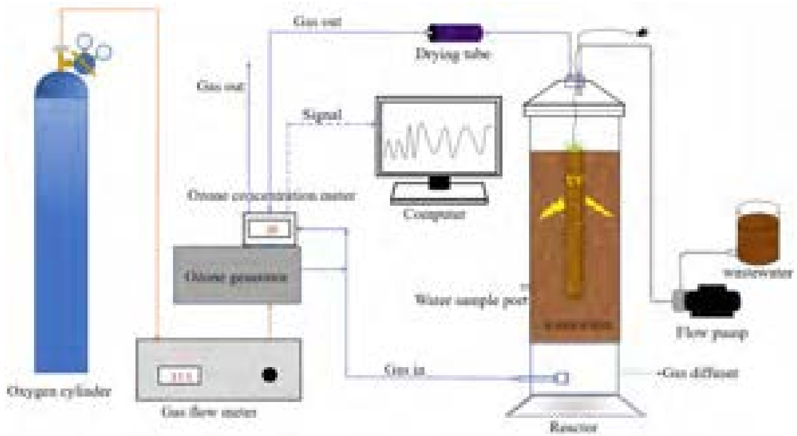


Fig. 1. Schematic representation of the experimental setup

Results and discussion

Comparison of Ortho-P production efficiency in UV, O_3 alone and O_3/UV processes

Synthetic wastewater containing HEDP was treated with three different processes, i.e. (i) UV, (ii) ozonation, (iii) ozonation with UV (O_3/UV). As shown in Figure 2, with increasing reaction time, both the single ozonation and O_3/UV processes exhibit an obviously increasing trend in Ortho-P generation efficiency, while little Ortho-P is generation is observed during the UV process. In the UV process, the generation efficiency of Ortho-P was below 5%. It indicates that UV process has almost no contribution to degrade phosphonates. The reactive species produced by UV alone are very limited and it is impossible to directly use the UV process for wastewater remediation. During the first 20 minutes there was no significant difference in the production efficiency of Ortho-P between ozonation and O_3/UV. A similar result was observed by Dong et al., when O_3 and UV/O_3 were used to treat marine oily wastewater[11]. It may be that the photons generated by UV can capture the free radicals in the system during O_3/UV process. After 20 minutes of reaction, compared with the ozonation alone, the production efficiency of Ortho-P treated by O_3/UV process was increase by 10%-25%. Ozonation alone has been used to treat phosphonate-contaminated wastewater to produce Ortho-P in previous works[12]. However, due to factors such as the mass transfer efficiency of ozone and the low efficiency of free radical generation, the production efficiency of Orth-P is not high. UV irradiation is considered as a useful addition to the ozonation process. The decomposition of O_3 can be promoted and the generation of hydroxyl radical [13].

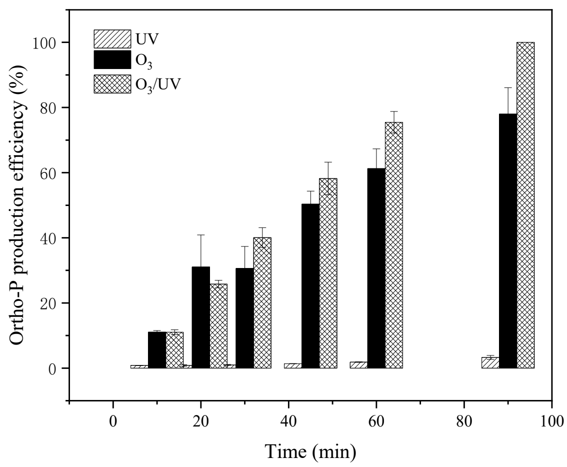


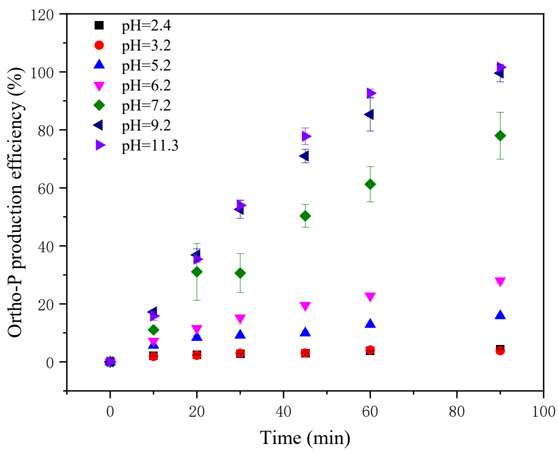
Figure 2. The Ortho-P production efficiency from phosphonate-contaminated wastewater after treatment with UV, O_3 and O_3/UV process. (Experimental conditions: ozone dose: 6 mg L^{-1} min^{-1}; gas flow rate: 0.6 L/min; initial pH=7.2; initial HEDP-P concentration = 100 mg/L, T=20± 2 °C)

Effect of pH on Ortho-P production efficiency

The pH of wastewater can vary greatly. The acidity and alkalinity of wastewater can have a significant impact on the formation of ROS in the O_3 or O_3/UV processes. For example, protons act as scavengers of active species, increasing the difficulty of acidic wastewater treatment. Thus, the effect of pH on Ortho-P production efficiency was systemically studied in this Section. Considering the UV process has a minimal effect on phosphonate degradation, the single UV process was not considered here.

It can be seen in Figure 3, when ozonation process was used to treat wastewater for 90 min, the production efficiency of Ortho-P increased from (4.4%) to (100%) as the pH increased from 2.4 to 11.3. This indicates that an alkaline environment is conducive to the production of Orth-P. Under alkaline environment, the decomposition of aqueous ozone is promoted, leading to the generation of a larger number of free radicals such as hydroxyl radicals and superoxide radicals [14]. In addition, the presence of H^+ can trap hydroxyl radicals, reducing the treatment efficiency.[15] [1] Thus, the Ortho-P production efficiency was always lower than 30% when the acidic wastewater (pH from 2.4 to 6.2) was treated by ozonation process [14]. More interestingly, the ortho-P production efficiency was significantly enhanced in alkaline wastewater (pH from 7.2 to 11.3) after 90 min of reaction. This indicates that ozonation alone is suitable for the treatment of alkaline wastewater. It is more difficult for the ozonation process to deal with wastewater with a large change in pH[1].

Different from the O_3 process, a high Ortho-P production efficiency was achieved in the O_3/UV process under different pH values. The Ortho-P production efficiency is still as high as 90% even in highly acidic wastewater. A similar result was obtained by Li et al[16]. They found that when UV/O_3/PDS process was used to AR73, the degradation efficiency of AR73 was almost the same at different pH. While the presence of H^+ has the ability to trap reactive species, their impact was not substantial enough to significantly impede the degradation of phosphonates in UV/O_3 process. This might be attributed to the fact that, despite inhibiting the decomposition of O_3, the presence of UV radiation still exerted a non-negligible influence on O_3 decomposition. As a result, the UV/O_3 process exhibited a broader pH adaptability. The application of ozone advanced oxidation can be extended with the aid of UV. This overcomes the problem that the single ozone process is difficult to deal with acidic wastewater.



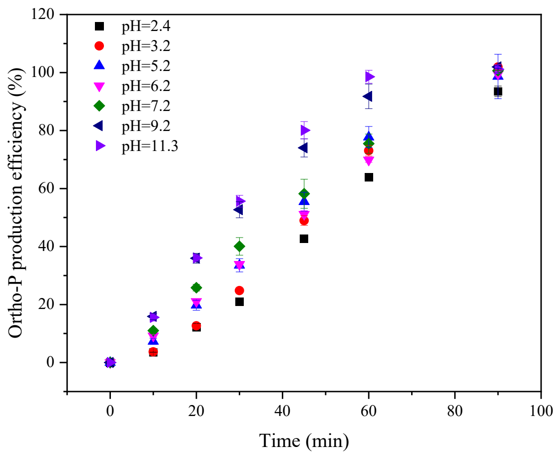


Figure 3. Effect of the initial pH on Ortho-P production from phosphonate-containing synthetic wastewater in single O_3 process (A) and O_3/UV process (B). (Experimental conditions: ozone dose: 6 mg min^{-1} L_{water}^{-1}; gas flow rate: 0.6 L/min; initial HEDP-P concentration = 100 mg/L, T=20± 2 °C)

Conclusions

In this study, UV, O_3, and O_3/UV processes were explored for the removal of typical phosphonate. The O_3/UV oxidation process resulted in the highest Ortho-P production efficiency (99%), followed by O_3 process (~80%) and UV process (<5%). Combining O_3 with UV promotes the decomposition of O_3 to produce free radicals, which is conducive to the production of Ortho-P. The effect of pH was systemically studied in O_3 and O_3/UV process. The Ortho-P production efficiency was always lower than 30% when the acidic wastewater (pH from 2.4 to 6.2) was treated by ozonation process. As such, it is difficult to deal with acidic wastewater when using the ozonation process. Different from the O_3 process, a high Ortho-P production efficiency was achieved in the O_3/UV process under different pH values.

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References:

[1] C. Chen, C. Ma, X. Yang, K. Demeestere, A. Nikiforov, S.W.H.V. Hulle, Phosphorus recovery from phosphonate-contaminated wastewater by nonthermal plasma treatment prior to adsorption on granular iron-coated sand, Chem Eng J. 464 (2023) 142753. https://doi.org/10.1016/j.cej.2023.142753.

[2] S. Sun, C. Shan, Z. Yang, S. Wang, B. Pan, Self-Enhanced Selective Oxidation of Phosphonate into Phosphate by Cu(II)/H2O2: Performance, Mechanism, and Validation, Environ Sci Technol. 56 (2022) 634–641. https://doi.org/10.1021/acs.est.1c06471.

[3] J. Ra, Y. Lee, Efficient degradation of ethanolamine by UV/chlorine process via organic chloramine photolysis: Kinetics, products, and implications for ethanolamine wastewater treatment, Chem Eng J. 412 (2021) 128631. https://doi.org/10.1016/j.cej.2021.128631.

[4] H. Irie, S. Miura, K. Kamiya, K. Hashimoto, Efficient visible light-sensitive photocatalysts: Grafting Cu(II) ions onto TiO2 and WO3 photocatalysts, Chem Phys Lett. 457 (2008) 202–205. https://doi.org/10.1016/j.cplett.2008.04.006.

[5] H. Eskandarloo, A. Badiei, M.A. Behnajady, TiO2/CeO2 Hybrid Photocatalyst with Enhanced Photocatalytic Activity: Optimization of Synthesis Variables, Ind Eng Chem Res. 53 (2014) 7847–7855. https://doi.org/10.1021/ie403460d.

[6] K. Kawaguchi, T. Hidaka, T. Fujiwara, A more selective and accurate method than indigo method for measuring dissolved ozone concentration (p-vinylbenzoic acid method), Water Res. 231 (2023) 119541. https://doi.org/10.1016/j.watres.2022.119541.

[7] A. Cruz-Alcalde, S. Esplugas, C. Sans, Abatement of ozone-recalcitrant micropollutants during municipal wastewater ozonation: Kinetic modelling and surrogate-based control strategies, Chem Eng J. 360 (2019) 1092–1100. https://doi.org/10.1016/j.cej.2018.10.206.

[8] L. Ling, Z. Deng, J. Fang, C. Shang, Bromate control during ozonation by ammonia-chlorine and chlorine-ammonia pretreatment: Roles of bromine-containing haloamines, Chem Eng J. 389 (2020) 123447. https://doi.org/10.1016/j.cej.2019.123447.

[9] W. Ren, L. Xiong, X. Yuan, Z. Yu, H. Zhang, X. Duan, S. Wang, Activation of Peroxydisulfate on Carbon Nanotubes: Electron-Transfer Mechanism, Environ Sci Technol. 53 (2019) 14595–14603. https://doi.org/10.1021/acs.est.9b05475.

[10] C. Liu, A.-Y. Zhang, D.-N. Pei, H.-Q. Yu, Efficient Electrochemical Reduction of Nitrobenzene by Defect-Engineered TiO2–x Single Crystals, Environ Sci Technol. 50 (2016) 5234–5242. https://doi.org/10.1021/acs.est.6b00730.

[11] G. Dong, B. Chen, B. Liu, Y. Cao, B. de Jourdan, S.R. Stoyanov, J. Ling, X. Ye, K. Lee, B. Zhang, Comparison of O3, UV/O3, and UV/O3/PS processes for marine oily wastewater treatment: Degradation performance, toxicity evaluation, and flocs analysis, Water Res. 226 (2022) 119234. https://doi.org/10.1016/j.watres.2022.119234.

[12] X. Yang, D. Manhaeghe, R. Zhang, S. Song, K. Demeestere, S.W.H.V. Hulle, Enhanced Production and Recovery of Orthophosphate from Wastewater Containing Phosphonate 1-Hydroxyethane-1,1-diphosphonic Acid through Combined Packed-Bed Ozonation and Adsorption, Acs Sustain Chem Eng. 9 (2021) 16946–16955. https://doi.org/10.1021/acssuschemeng.1c05260.

[13] J. Wang, H. Liu, Y. Gao, Q. Yue, B. Gao, B. Liu, K. Guo, X. Xu, Pilot-scale advanced treatment of actual high-salt textile wastewater by a UV/O3 pressurization process: Evaluation of removal kinetics and reverse osmosis desalination process, Sci Total Environ. 857 (2023) 159725. https://doi.org/10.1016/j.scitotenv.2022.159725.

[14] N. Huang, Z. Xu, W.-L. Wang, Q. Wang, Q.-Y. Wu, H.-Y. Hu, Ozonation of phosphonate antiscalant 1-hydroxyethane-1,1-diphosphonic acid in reverse osmosis concentrate: Kinetics, phosphorus transformation, and anti-precipitation property changes, Sep Purif Technol. 297 (2022) 121385. https://doi.org/10.1016/j.seppur.2022.121385.

[15] B. Jiang, J. Zheng, Q. Liu, M. Wu, Degradation of azo dye using non-thermal plasma advanced oxidation process in a circulatory airtight reactor system, Chem Eng J. 204 (2012) 32–39. https://doi.org/10.1016/j.cej.2012.07.088.

[16] Y. Lin, J. Chen, H. Li, L. Chen, B. Yuan, C. Shi, S. Li, G. Liu, Y. Xie, Synergistic and efficient degradation of acid red 73 by UV/O3/PDS: Kinetic studies, free radical contributions and degradation pathways, Environ Res. 216 (2023) 114449. https://doi.org/10.1016/j.envres.2022.114449.

Framework elaboration for the development of hybrid modelling for resource recovery from municipal wastewater and impact mitigation in Gotland/SE.

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Keywords: wastewater, sustainability, resource recovery, system dynamics modelling, agent-based modelling, hybrid models

ABSTRACT

The emerging concern about the scarcity of natural resources has created a planetary dilemma that involves social, economic, and political factors at the micro, meso, and macro institutional levels. The biggest challenges for the sustainability transition worldwide are related to climate change associated with rapid population growth (Francisco *et al.*, 2023). Rapid population growth and urbanization have resulted in increased demand for sewage treatment. Wastewater treatment plants (WWTPs) are identified as energy-intensive operations and representative sources of greenhouse gas (GHG) emissions. The transformation or recovery of recovering nutrients from wastewater presents an opportunity for the transition from services to net-zero wastewater services.

The Baltic Sea, one of the most eutrophic seas in the world and located in Northern Europe, is a vulnerable, brackish, semi-enclosed sea, suffering from high pressures from human activity. Such factors lead to an increase of hypoxic and anoxic areas (Almroth-Rosell *et al*., 2021). According to Rabalais *et al*. (2010), the spread of hypoxia (low oxygen) and anoxia (no oxygen) areas in coastal waters is mainly due to eutrophication caused by nutrient enrichment from intensified agriculture and wastewater discharges since the mid-20th century, as detected in the Gotland basins. According to studies, a downward trend in nutrient concentrations related to eutrophication is observed in some parts of the Baltic Sea. The results show this trend in the reduction of phosphorus loads from municipal effluents; however, nitrogen loads are stable or show temporary increases (Preisner *et al*., 2021). Gotland is Sweden's largest island, located in the Baltic Sea, about 100 km from the mainland and population round is about 61,173, just a fraction of the vast number of visitors. In 2023 over 2 million people travelled to Gotland, and the number of guest nights at hotels and other commercial accommodation facilities exceeded 768,000 (Region Gotland, 2023). The peak season for tourism is during the summer, resulting in a large seasonal variation in water demand and wastewater production.

Since the environmental context of the Gotland region, aggravated by the increase in tourism, can accelerate the process of eutrophication in the Baltic Sea, the study in question aims to present a framework for the development of hybrid modelling in a sustainability and trade-off analysis for recovering nutrients/energy from wastewater. According to Bokor *et al*. (2019) the use of basic simulation method in high complexity system might not be enough to obtain appropriately feedback, so hybrid approaches are needed. The proposal is based on coupling system dynamics and agent-based modelling in the development of predictive scenarios considering technological aspects of WWTPs and the perspective of stakeholders in the adoption of technologies aimed at the transition to more sustainable systems.

Methodology

A model corresponds to a formal and simplified representation of reality and cannot be so simple as to lead to errors in the analysis of the situation studied, nor so complex as to classify it as intractable (Almeida, 2013). The construction of models for simulation takes place through the organization of steps that allow the understanding of complex problems. Hybrid approaches have been gaining prominence due to overcoming limitations of traditional methodologies and tools, as well as computational advances that permit better modelling and analysis of complex systems, as in the case of sustainability approach (Demartini *et al*., 2018). In this study, a hybrid approach based on Agent-Based and System Dynamics modelling is presented in order to improve modelling insight of a symbiosis of social and environmental nature.

The System Dynamics Modelling (SDM), which is widely used in the modelling and simulation of complex systems to understand interrelations between components (Forrester, 1961; 1968). The SDM is often used to quantify behaviours in recursive cycles that present feeding and feedback relationships between relevant factors of a certain system, allowing analyses of potential trade-offs in scenarios that have multiple attributes. The time dimension is considered by the relations in the diagram between stocks and flows (quantitative key variables that interconnect stocks), simulating the system dynamics (Chhipi-Shrestha *et al*., 2017).

The diversity of Agent-Based Modelling (ABM) and simulation application areas is truly remarkable and continues to grow. Applications range in virtually all areas of the natural, social and physical sciences, as well as in systems engineering and far beyond the usual methodologies of simulation, business management, and production process operations. A typical agent-based model has three elements: a) a set of agents, their attributes and behaviours; b) a set of agent relationships and interaction methods - an underlying connection topology defines how and with whom agents interact; c) the agents' environment - agents interact with their environment, in addition to other agents and their respective environments. Furthermore, it is proposed the selection of indicators (economic, social, environmental) to be considered as outputs parameters (Macal & North, 2010; 2014). This strategy aims to analyse sustainability from the simulation of predictive scenarios.

Due to the consequent problems described in the region of the island of Gotland, caused by environmental and social factors, the study adopted the effluent treatment plant in the city of Visby, the city with the highest popular and tourist concentration in the region. The wastewater treatment plant (WWTP) processes approximately 8,000m^3 of wastewater per day. The Moving Bed Biofilm Reactor (*MBBR*) *wastewater treatment* process consists of a biostage, with pre-denitrification, BOD and nitrification basins, where dissolved organic matter is purified and ammonium nitrogen is converted to nitrate nitrogen. The discharge line opens at a depth of 7 meters 140 m from the shore dumping the treated effluent, containing fractions of carbon organic, nitrogen and phosphorus, into the Baltic Sea. The sludge produced in the WWTP is pumped to a digester where it undergoes digestion in two stages. The digested gas produced is used for heating internal sludge for digestion chambers, heat in the treatment plant's premises, vehicle gas, and any excess is led to Geab's district heating system. The digested sludge is then pumped to a sludge layer, after which it is centrifuged for further transport to an intermediate storage plate. The fertilizer from the sludge is sent to small producers from Gotland and to recycling station from continent (Region Gotland, 2023).

Results

The Figure 1 shows the causal loop diagram developed aiming to understand the interrelationships between the wastewater generation and their consecutive treatment in the WWTPs.

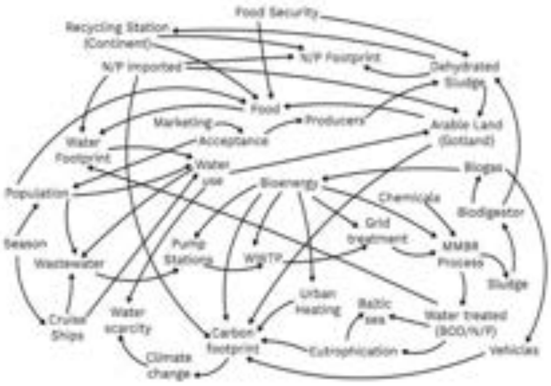

Figure 1: Causal loop from wastewater environment in Visby.

The next step consisted of design a hybrid SD-ABM model (Figure 2) considering the structure of Visby's WWTP. As inputs parameters, technologies for recovery and/or transformation of nutrients into energy will be evaluated, as well as inputs necessary for the operation. Aiming at optimizing nutrient recovery processes or energy generation, the developed framework presents three additional systems to the current treatment process. As output for the simulations and respective scenarios, in a future stage, eutrophication and the footprints for water, carbon, nitrogen and phosphorus were selected as environmental indicators. The systems being proposed are: a) Urine system: a pre-step of urine separation will be analysed for selected pump stations and their interference in environmental parameters according to the methodology proposed by Simba *et al*. (2022, 2023); b) Biotechnology system: alternative biotechnological processes will be evaluated, such as the application of microalgae in the bioconversion of residual pollutants present in the treated effluent into bioproducts (biofertilizer, bioenergy, carotenoids, among others) as a platform for biorefineries (Francisco *et al*., 2015); c) Agent-based system: the system will simulate the aspects that represent the ABM part of the model. Behaviors involving different stakeholders (population, food producers, and government) and current legislation that addresses food security and environmental preservation issues will be simulated.

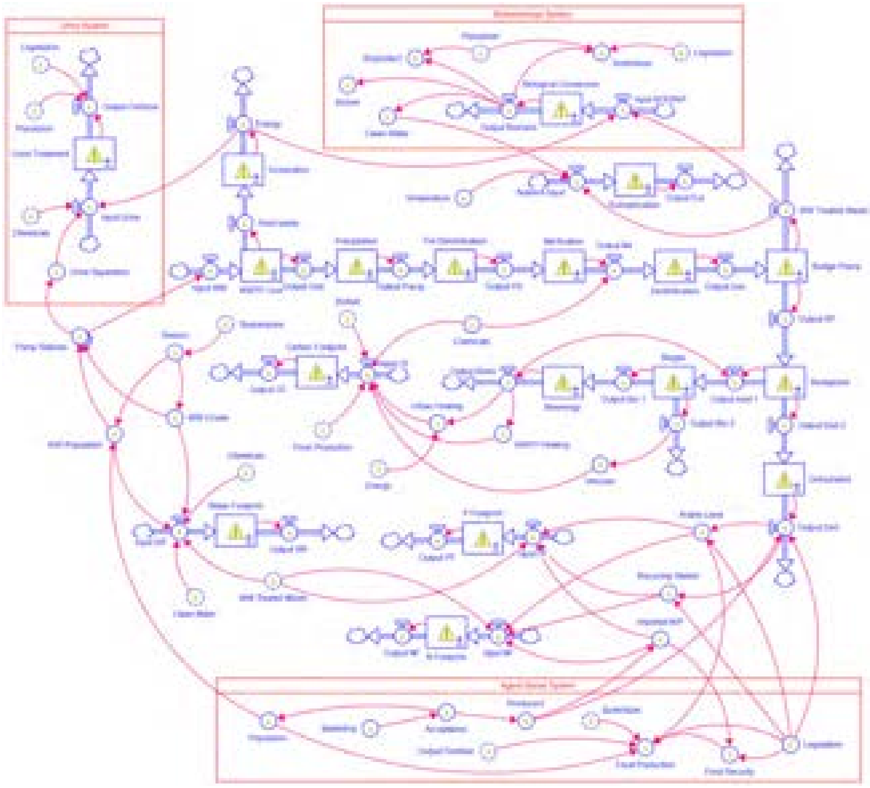

Figure 2: SD-ABM hybrid model framework for Visby's WWTP.

Conclusion and Next Steps

In high-income countries, most domestic wastewater is collected and treated in wastewater treatment plants (Martin *et al*., 2023). As in the case of Visby's WWTP, the sludge issued from the WWTP treatments can be recycled in agricultural practices. For example, approximately 75% of the sewage sludge generated in France is recycled in this way (Collivignarelli *et al*., 2019). However, studies point out negative factors for this methodology, such as a very low proportion of recycled nitrogen in addition to denitrification is an energy-intensive treatment (Esculier *et al*., 2018; Maurer *et al*., 2003). Since most of the nutrients in wastewater come from urine: approximately 80% of the nitrogen, 50% of the phosphorus and 70% of the potassium (Martin *et al*., 2023), the "Urine system" will be evaluated in predictive scenarios considering technical and social factors to produced fertilizer and increase the food production on the island of Gotland.

MBBR systems are recognized for their efficiency in treating effluents, however, it is well known that a significant proportion of nitrogen and phosphorus and potassium remains and is discharged to the surface water. In the WWTP in question, Bod 40 kg, Total nitrogen 80 kg and Total phosphorus 2 kg are issued daily. The "Biotechnology system" will evaluate the recovery of this fraction of nutrients as well as the efficiency in converting biomass into different bioproducts.

The social factor such as the acceptance of stakeholders for the use of fertilizers from wastewater recycling, as well as the consumption of food produced with such inputs, will be simulated by the "Agent-based system". The legislation on the application of recycled fertilizers and food safety will also be considered. Finally, the next steps include organizing a database for efficient simulation and validation of the model using statistical tools, and meetings with the community to capture their perspective and design predictive scenarios.

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References:

Almeida, A.T., 2013. Processo de Decisao nas Organizaçoes, 1 edn. Construindo modelos de decisao multicriterio, Sao Paulo: Editora Atlas S.A. ISBN-13: 978–8522480111.

Almroth-Rosell, E., Wåhlström, I., Hansson, M., Väli, G., Eilola, K., Andersson, P., Viktorsson, L., Hieronymus, M., Arneborg, L., 2021. A Regime Shift Toward a More Anoxic Environment in a Eutrophic Sea in Northern Europe. Front. Mar. Sci. 8:799936. https://doi.org/10.3389/fmars.2021.799936

Bokor, O., Florez, L., Osborne, A., Gledson, B.J., 2019. Overview of construction simulation approaches to model construction processes. Organization, Technology and Management in Construction, 11: 1853-1861. https://doi.org/10.2478/otmcj-2018-0018

Chhipi-Shrestha, G., Hewage, K., Sadiq, R., 2017. Water-Energy-Carbon Nexus Modelling for Urban Water Systems: System Dynamics Approach. J. Water Resour. Plann. Manag, 143, 04017016. https://doi.org/10.1061/(ASCE)WR.1943-5452.0000765

Collivignarelli, M.C., Abb`, A., Frattarola, A., Carnevale Miino, M., Padovani, S., Katsoyiannis, I., Torretta, V., 2019. Legislation for the reuse of biosolids on agricultural land in Europe: overview. Sustainability 11, 6015. https://doi.org/ 10.3390/su11216015.

Demartini, M., Tonelli, F., Bertani, F., 2023. Approaching Industrial Symbiosis Through Agent-Based Modeling and System Dynamics. Service Orientation in Holonic and Multi-Agent Manufacturing, Studies in Computational Intelligence 762, https://doi.org/10.1007/978-3-319-73751-5_13

Forrester J.W. 1961. Industrial dynamics. MIT Press, Cambridge, MA. ISBN, 0262060035

Forrester J.W. 1968. Principles of system dynamics. Productivity Press, Cambridge, MA. https://doi.org/10.1007/978-1-4419-6281-2_20

Francisco, E.F., Franco, T.T., Zepka, L.Q., Jacob-Lopes, E., 2015. From waste-to-energy: the process integration and intensification for bulk oil and biodiesel production by microalgae. Journal of Environmental Chemical Engineering, 3, 482–487. DOI: 10.1016/j.jece.2014.12.017

Francisco, E.F., Piolli, A.L., Ignácio, P.S.A., Dal Poz, M.E.S., 2023. Food-Energy-Water (FEW) nexus: Sustainable food production governance through system dynamics modelling. Journal of Cleaner Production, 386, 135825. https://doi.org/10.1016/j.jclepro.2022.135825.

Macal, C.M., North, M.J., 2010. Tutorial on agent-based modelling and simulation. *Journal of Simulation*. Special issue on agent-based modelling, 4(3), 151–162.

Macal, C.M., North, M.J., 2014. Introductory tutorial: Agent-based modeling and simulation. In: Tolk, A.; Diallo, S.D.; Ryzhov, I.O.; Yilmaz, L.; Buckley, S.; Miller, J.A. (eds). *Proceedings of the 2014 Winter Simulation Conference*, Savannah, Georgia, USA, 7–10.

Maurer, M., Schwegler, P., Larsen, T.A., 2003. Nutrients in urine: energetic aspects of removal and recovery. Water Sci. Technol. 48, 37–46. https://doi.org/10.2166/wst.2003.0011.

Martin, T.M.P., Aubin, J., Gilles, E., Auberger, J., Esculier, F., Levavasseur, F., McConville, J., Houot, S., 2023. Comparative study of environmental impacts related to wheat production with human-urine based fertilizers versus mineral fertilizers. Journal of Cleaner Production, 382, 135123. https://doi.org/10.1016/j.jclepro.2022.135123

Preisner, M., Smol, M., 2021. Dominika Szołdrowska1. Trends, insights and effects of the Urban Wastewater Treatment Directive (91/271/EEC) implementation in the light of the Polish coastal zone eutrophication. Environmental Management, 67:342–354. https://doi.org/10.1007/s00267-020-01401-6

Rabalais, N. N., Diaz, R. J., Levin, L. A., Turner, R. E., Gilbert, D., and Zhang, J., 2010. Dynamics and distribution of natural and human-caused hypoxia. Biogeosciences 7, 585–619. https://doi.org/10.5194/bg-7-585-2010

Region Gotland, 2023. https://www.gotland.se/visbyreningsverk (accessed 20 June 2023)

Simha, P., Deb, C.K., Randall, D.G., Vinnerås, B., 2022. Thermodynamics and Kinetics of pH-dependent Dissolution of Sparingly Soluble Alkaline Earth Hydroxides in Source Separated Human Urine Collected in Decentralised Sanitation Systems. Front. Environ. Sci. 10:889119. https://doi.org/10.3389/fenvs.2022.889119

Simha, P., Vinnerås, B., Dyllon, G.R., 2023. Factors influencing the recovery of organic nitrogen from fresh human urine dosed with organic/inorganic acids and concentrated by evaporation in ambient conditions. Science of the Total Environment, 879, 163053. http://dx.doi.org/10.1016/j.scitotenv.2023.163053

EXPLORING THE POTENTIAL OF CYANOBACTERIAL MICROBIOMES FOR SUSTAINABLE BIOPRODUCTS

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Keywords: Polyhidroxyalkanoate, Photosynthetic Culture, Bioplastic,

ABSTRACT

INTRODUCTION

Environmental biotechnologies that involve using cyanobacteria to generate bioproducts are faced with unique challenges. Despite numerous articles and reviews showcasing the exceptional potential of cyanobacteria for producing bioproducts [1–3], their full-scale application outside of the food industry remains limited. This is likely due to several factors, including the availability of affordable raw materials, inadequate regulations, and a lack of viable business models. However, the main obstacle appears to be the significant research gaps in understanding how to cultivate cyanobacterial cultures and create appropriate culture conditions for the desired bioproducts. These gaps are currently preventing the development of cyanobacterial biotechnologies, and it is crucial to address them in order to fully tap into their potential. To overcome these challenges, we propose utilizing cyanobacterial microbiomes.

Cyanobacteria are capable of producing various bioproducts, but one product in particular, polyhydroxybutyrate (PHB), has garnered significant interest due to its potential as a sustainable alternative to petroleum-based plastics [4]. PHB can be accumulated by cyanobacteria under nutrient-limited conditions [5–9]; however, the amount of PHB produced by monocultures of cyanobacteria is relatively low, with wild-type strains producing up to 25% dry cell weight (dcw) of PHB [6,10]. To increase production, researchers have employed molecular biology techniques. However, to make PHB production economically feasible and competitive with current plastic markets, it is important to avoid using genetically engineered strains. Instead, adding an organic carbon source, such as acetate, significantly boost biosynthesis [6,11,12].

In addition, maintaining productive cyanobacterial cultures for the long-term generation of bioproducts of interest is also a major challenge. Unfortunately, most research undertaken to date has been limited to small-scale experiments with a short time frame, typically lasting only a few weeks [9,10,13].

In line of the above, in this study, various photosynthetic microbiomes were evaluated for their ability to produce PHB. These cultures were obtained from environmental samples and enriched with cyanobacteria using low phosphorus concentration as a selective pressure. To boost biopolymer production, two approaches were employed: (1) altering operating parameters known to affect PHB synthesis, and (2) optimizing the culture to increase the presence of PHB-producing organisms.

MATERIALS AND METHODS

Procurement of photosynthetic cultures

Seven samples were collected from four different locations (constructed wetland, river, canal and urban lake) in the metropolitan area of Barcelona, Spain. Samples were grown in laboratory conditions to obtain microbiomes enriched in cyanobacteria. Phosphorus (P) limitation was used to favour the growth of cyanobacteria against other phototrophic organisms (i.e. green algae). Cultures were maintained with a P concentration in the flasks of 0.2 mg·L^{-1}.

Microbial identification

The identification and classification of Cyanobacteria present in the microbiomes were performed using a combination of morphological observation under a bright light microscope and molecular characterization via clone library analysis of the 16S rRNA gene.

Design of Experiments

The metabolic regime was evaluated by experiments combining three factors: (i) the presence of organic carbon (OC), (ii) inorganic carbon (IC) and (iii) light:dark photoperiods. Multivariable experimental design (DoE) and surface response methodology (SRM) were used [6]to identify the optimal conditions and evaluate their effect on PHB production.

Enriching biomass in PHB-producing organisms

A new technique based on the Feast and Famine (FF) strategy, commonly used in PHB production by heterotrophic cultures, was implemented to enhance PHB production by cyanobacteria-enriched microbiomes. The study utilized a Sequencing Batch Reactor (SBR) and was applied to three different microbiomes for 209 days (microbiome 1) and 100 days each (microbiomes 2 and 3) in 3L photobioreactors (PBRs). During PBR operation, growth and starvation were systematically carried out to selectively enrich the microbiome with microorganisms capable of producing PHB.

RESULTS AND DISCUSSION

Effect of selective pressure on field environmental samples

The effectiveness of the selection pressure applied to favor cyanobacteria over other microorganisms was confirmed through a combination of microscopic observation using both a bright light and fluorescence microscope, as well as molecular analysis of the 16S rRNA gene. The microscopic observations revealed the presence of filamentous and punctate colony-forming cyanobacteria (Figure 1). The results of the 16S rRNA analysis further showed that this selection pressure (P limitation) resulted in a decrease in the number of bacterial populations in the environmental samples collected and a significant increase in the presence of cyanobacteria in the microbiomes.

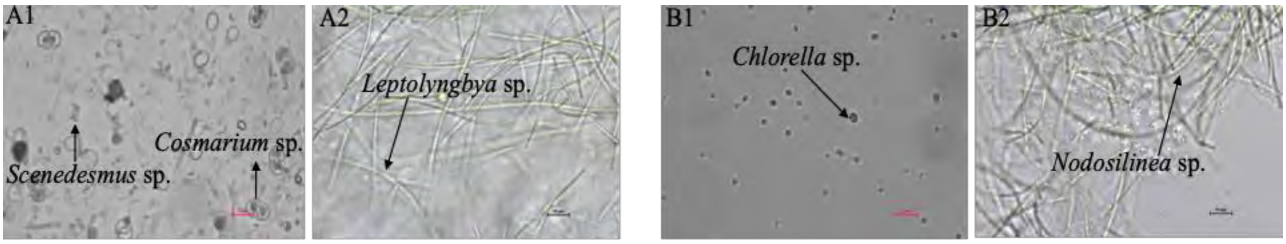


Figure 1. Microscope images of microbiomes under bright light microscopy at 400X. Panel A) corresponds to “microbiome 1” and B) corresponds to “microbiome 2”. A1) and B1) correspond to samples of field environmental microbiomes. The scale bar is 20μm. A2) and B2) correspond to cyanobacteria-enriched microbiomes after 5 months of growth with P limitation. The scale bar is 10 μm.

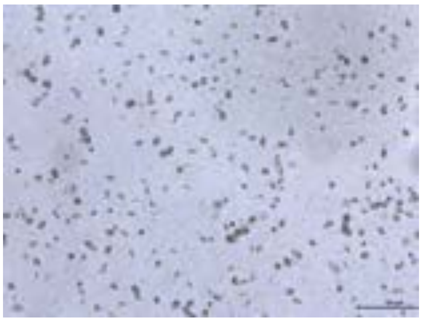
Enhancing PHB production through the optimization of operating conditions

The study found that the optimal conditions for biopolymer synthesis were dependent on the specific microbiome being tested, however, the results from the Design of Experiment (DoE) revealed that higher PHB contents were obtained when the cultures were grown under heterotrophic or mixotrophic conditions. Additionally, the results showed that the addition of organic carbon was the sole factor that had a consistent impact on biopolymer production across all microbiomes tested. The highest PHB content, reaching 14 % dry cell weight, was achieved for one specific microbiome by adding 1.2 g of acetate per liter and maintaining a light:dark photoperiod of seven days. Based on these results, the microbiome and the best conditions for bioproduct synthesis were selected for further scaling up.

Enhancing PHB production by enriching biomass in PHB-producer organisms

To enhance PHB synthesis, the feast and famine (FF) strategy was applied to selectively enrich the microbiomes with microorganisms that exhibited higher PHB production in the previous Design of Experiment (DoE) studies. The first microbiome tested, rich in the unicellular cyanobacteria *Synechococcus* sp., filamentous cyanobacteria *Leptolyngbya* sp., and green algae, was operated for 209 days with 9 repeated FF cycles. In addition, the impact of three parameters (nutrient concentration, temperature, and light) on biomass growth and biopolymer synthesis was evaluated beforehand to establish optimal conditions for operating the PBRs. We observed a substantial increase in PHB production from 2 %dcw PHB in the first phase to 22 %dcw PHB, however, the presence of green algae caused a decline in PHB production and posed a challenge to maintaining the stability of the microbiome (Figure 2 A-B). While controlling P concentration or temperature could promote the survival of cyanobacteria over green algae, the abundance of the latter can exceed controllable limits, resulting in green algae outcompeting. To validate these results, two additional microbiomes were operated under the selected conditions. The first was rich in cyanobacteria *Synechococcus* sp. and green algae, while the second was rich in the unicellular cyanobacteria *Synechocystis* sp. and *Synechococcus* sp. Interestingly, in the microbiome containing green algae, PHB production was relatively low and showed great variability between PBRs (Figure 2 C-D). However, when the PBR operation was applied to a microbiome consisting only of cyanobacteria, PHB production remained constant in all the starvation phases over the experimental period of 100 days. On average, cells accumulated 27.1 %dcw PHB in 14 days, demonstrating robust PHB production (Figure 2 E-F), while maintaining the species composition of the microbiome.

A



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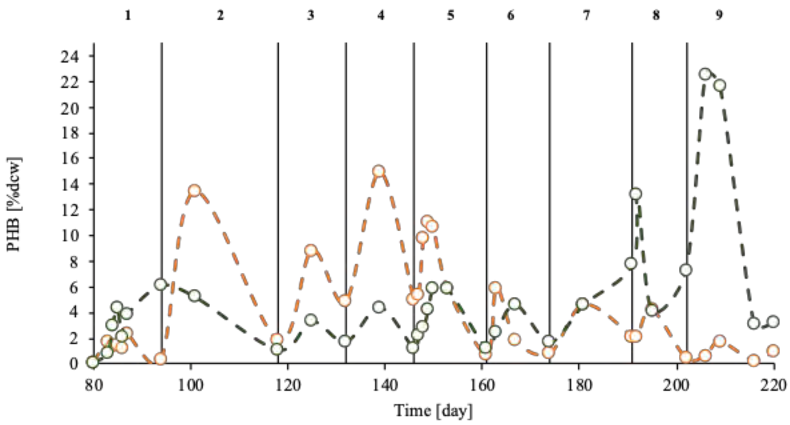

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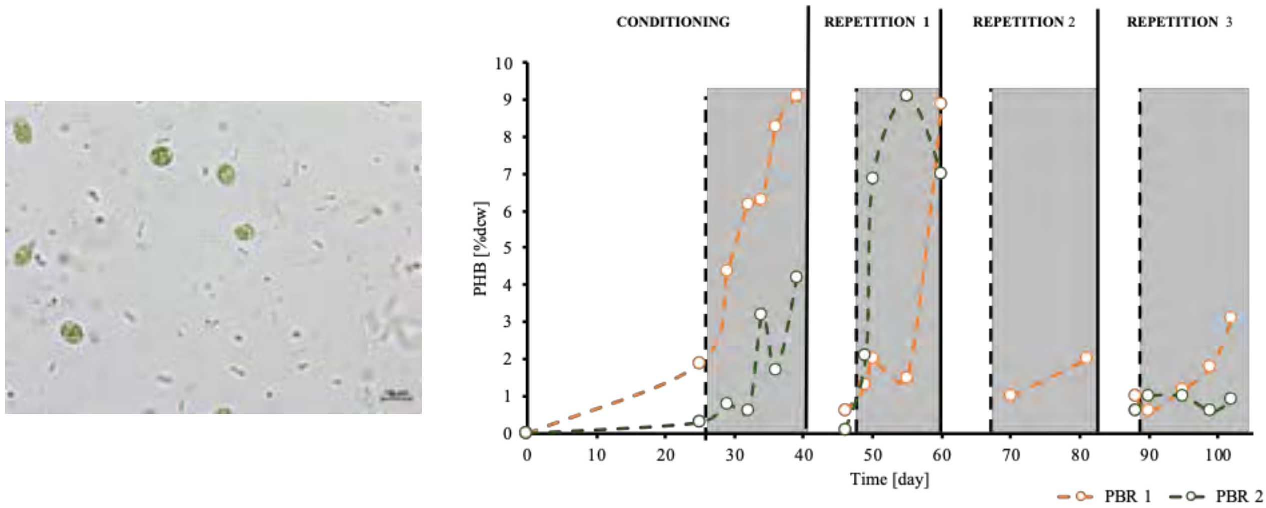

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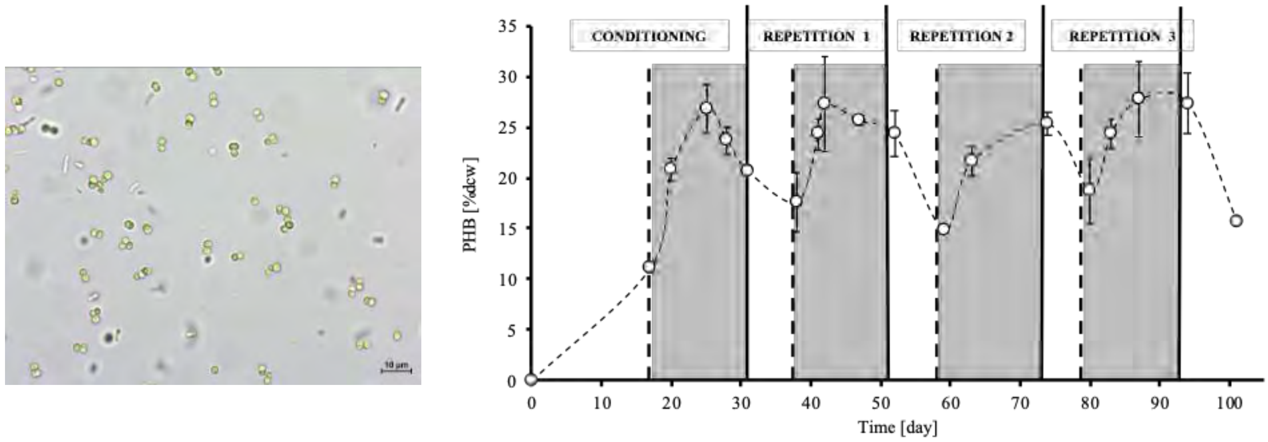

Figure 2. PHB evolution over the FF strategy for microbiome optimization on PHB-producer microorganisms for 3 different microbiomes.

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References:

[1] M. Borowitzka, Commercial-Scale Production of Microalgae for Bioproducts, in: Blue Biotechnol., 2018: pp. 33–65. https://doi.org/10.1002/9783527801718.ch2.

[2] D. Cruz, V. Vasconcelos, G. Pierre, P. Michaud, C. Delattre, Exopolysaccharides from cyanobacteria: Strategies for bioprocess development, Appl. Sci. 10 (2020). https://doi.org/10.3390/app10113763.

[3] S.S. Costa, A.L. Miranda, M.G. de Morais, J.A.V. Costa, J.I. Druzian, Microalgae as source of polyhydroxyalkanoates (PHAs) — A review, Int. J. Biol. Macromol. 131 (2019) 536–547. https://doi.org/10.1016/j.ijbiomac.2019.03.099.

[4] G.-Q. Chen, Industrial Production of PHA, 14 (2010) 121–132. https://doi.org/10.1007/978-3-642-03287-5_6.

[5] E. Rueda, M.J. García-Galán, R. Díez-Montero, J. Vila, M. Grifoll, J. García, Polyhydroxybutyrate and glycogen production in photobioreactors inoculated with wastewater borne cyanobacteria monocultures, Bioresour. Technol. 295 (2020) 122233. https://doi.org/10.1016/j.biortech.2019.122233.

[6] E. Rueda, B. Altamira-Algarra, J. García, Process optimization of the polyhydroxybutyrate production in the cyanobacteria Synechocystis sp. and Synechococcus sp., Bioresour. Technol. 356 (2022) 127330. https://doi.org/10.1016/J.BIORTECH.2022.127330.

[7] P.R. Yashavanth, M. Das, S.K. Maiti, Recent progress and challenges in cyanobacterial autotrophic production of polyhydroxybutyrate (PHB), a bioplastic, J. Environ. Chem. Eng. 9 (2021). https://doi.org/10.1016/j.jece.2021.105379.

[8] S. Ansari, T. Fatma, Cyanobacterial Polyhydroxybutyrate (PHB): Screening, Optimization and Characterization,

PLoS One. 11 (6) (2016). https://doi.org/10.1371/journal.pone.0158168.

[9] T. Monshupanee, A. Incharoensakdi, Enhanced accumulation of glycogen, lipids and polyhydroxybutyrate under optimal nutrients and light intensities in the cyanobacterium Synechocystis sp. PCC 6803, J. Appl. Microbiol. 116 (2014) 830–838. https://doi.org/10.1111/jam.12409.

[10] B. Panda, P. Jain, L. Sharma, N. Mallick, Optimization of cultural and nutritional conditions for accumulation of poly-β-hydroxybutyrate in Synechocystis sp. PCC 6803, Bioresour. Technol. 97 (2006) 1296–1301. https://doi.org/10.1016/j.biortech.2005.05.013.

[11] M. Simonazzi, L. Pezzolesi, P. Galletti, C. Gualandi, R. Pistocchi, N. De Marco, Z. Paganelli, C. Samorì, Production of polyhydroxybutyrate by the cyanobacterium cf. Anabaena sp., Int. J. Biol. Macromol. 191 (2021) 92–99. https://doi.org/10.1016/j.ijbiomac.2021.09.054.

[12] B. Panda, N. Mallick, Enhanced poly-b-hydroxybutyrate accumulation in a unicellular cyanobacterium, Synechocystis sp. PCC 6803, Lett. Appl. Microbiol. 44 (2007) 194–198. https://doi.org/10.1111/j.1472-765X.2006.02048.x.

[13] W. Khetkorn, A. Incharoensakdi, P. Lindblad, S. Jantaro, Enhancement of poly-3-hydroxybutyrate production in Synechocystis sp. PCC 6803 by overexpression of its native biosynthetic genes, Bioresour. Technol. 214 (2016) 761–768. https://doi.org/10.1016/j.biortech.2016.05.014.

Electrocoagulation flotation treatment technology in perspective of resource recovery and reuse of municipal wastewater in different regions of the world

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Keywords: Electrocoagulation flotation, municipal wastewater treatment, sludge management , sustainability, circular economy.

ABSTRACT

Continuous Electrocoagulation Flotation (ECF) is an innovative and sustainable treatment technology for municipal wastewater (MWW) that facilitates resource recovery and reuse. The characteristics of ECF include simplicity, the ability to remove organic and inorganic contaminants, in-situ disinfection, and low sludge generation (Ingelsson et al., 2020). Resource recovery is possible through biogas production and the reclamation of phosphate and metals from ECF sludge. The ECF technology has been widely applied for industrial wastewater treatment and is now being considered for MWW treatment. However, the operating performances of ECF technology in terms of energy efficiency and pollutant removal are determined by MWW characteristics such as (particulate) organic content, pH, and electrical conductivity (EC) (Ingelsson et al., 2020). Nevertheless, the varying effluent quality legislation for surface water discharge and reuse across the world makes it challenging to establish uniform optimal ECF operating parameters for MWW treatment. Regulatory disparities between Belgium and Bangladesh impact the potential for reusing and recovering ECF-treated MWW and its sludge. To globally implement ECF technology for MWW treatment and promote it as a green technology, regional optimization of operating parameters is necessary. This study aimed to compare the ECF treatment of MWW in Khulna, Bangladesh, and Kortrijk, Belgium.

The research utilized three types of MWW (Table 1): 1) freshly collected influent from the municipal wastewater treatment plant (MWWTP) in Harelbeke, Belgium, operated by Aquafin (Chys et al., 2018) (MWW BE), 2) NaCl spiked MWW from the same MWWTP to simulate Khulna City MWW (MWW NaCl BE) (Haldar et al., 2020), and 3) real MWW from Khulna City, Bangladesh (MWW BD). For the Belgian MWW, influent was collected before the primary treatment unit. In contrast, for the Bangladeshi MWW, 5 L of influent was collected from each of the 5 outfalls, prior to discharge into surrounding rivers, of the combined sewage transport network in Khulna City (Haldar et al., 2020). It is important to note that Khulna City lacks a MWWTP, and the sewerage transport network functions as an open drain system. The ECF reactor used in the experiments with sacrificial iron (Fe) anode and inert stainless steel (SS) cathode is described elsewhere (Parmentier et al., 2020).

To achieve specific current densities (CD), constant currents of 1 Amp and 2 Amp were employed, resulting in CD of 40 and 80 A/m², respectively. A flow rate of 10 L/h was applied for all three types MWW treatments using the same ECF reactor. Optimized performances were evaluated based on removal of total chemical oxygen demand (tCOD), total phosphate (TP), total nitrogen (TN), total suspended solid (TSS), *Escherichia coli* (E. coli) and Fecal Coliform. Total solid (TS) and dry solid (DS) contains of ECF sludge were measured. All the abovementioned analysis and measurements were conducted following standard procedures and methods (APHA, 1992, Parmentier et al.,2020). Produced sludge volume were also recorded during each experiments, i.e., ml sludge produced /L MWW treated. Heavy metals analysis were also performed following Lakho et al., 2020. Anaerobic digestion were done for ECF sludge biogas potential assessment following Schroyen et al., 2014. Also operational efficiency evaluated based on Faraday efficiency, i.e., applied CD efficiency to dissolved

metal from anode and H_2 (g) microbubble formation from cathode, and total operational expenses (OPEX) i.e., sum of energy and electrode consumption according to Parmentier et al. (2020).

Table 1: Different MWW's influent characteristics used in the study for ECF treatment.

Parameter	MWW BE	MWW NaCl BE	MWW BD	Parameter	MWW BE	MWW NaCl BE	MWW BD
pH	7.88±0.2	7.73±0.3	7.57±0.1	**TSS(mg/L)**	693±176	1438±140	111±30
DO(mg/L)	3.52±1.7	2.80±1.5	1.42±0.9	**Ca (mg/L)**	182.58±32	181.49±32	138.67±97
EC(µS/cm)	1146±455	2046±278	1930±142	**Mg (mg/L)**	25.13±17	25.42±17	94.33±5
Turbidity (NTU)	310±494	465±698	38±2	**Na (mg/L)**	186.08±35	424.02±38	344.86±39
tCOD(mg/L)	400±322	327±274	318±138	**K (mg/L)**	29.47±5	29.14±4	25.67±17
TP(mg/L)	6±5	6 ±5	10 ±2	**Cl^- (mg/L)**	260.76±71	518.33±51	611.32±66
TN(mg/L)	64±28	64±28	72 ±48	**SO_4^{2}(mg/L)**	164.50±93	162.17±92	190.38±40

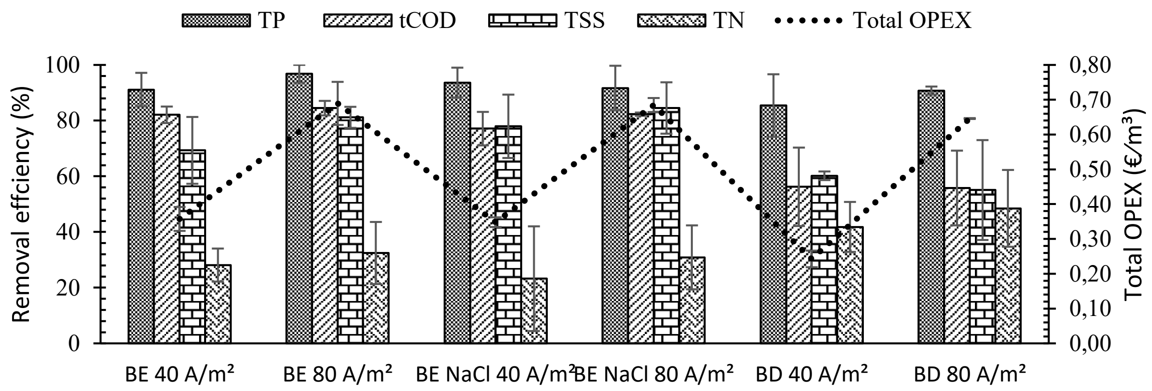

Figure 1: Removal efficiency (%) of TP, tCOD, TSS and TN, and Total OPEX in the ECF process at two CD: 40 and 80 A/m^2. The experiments involved treating MWW BE (n=3), MWW NaCl BE (n=3), and MWW BD (n=3).

Figure 1 illustrated that the ECF technology effectively removes tCOD, TP, and TSS from all types of MWW samples. The removal efficiency, either interms of percentage (%) or concentration, of tCOD, TP, and TSS meets the effluent discharge standards of the EU Directive 91/271/EEC for Belgium and Environmental Bangladesh Conservation Rule 2023 (ECR 2023) for Bangladesh. Green rust (GR) formation in Fe-based ECF systems is highly effective in removing organic matter and heavy metals (Ingelsson et al., 2020). In addition, the specific floc-tower design of the ECF reactor, combined with the flotation induced by H_2(g) microbubbles, enables enhanced sweep coagulation (Parmentier et al., 2020).

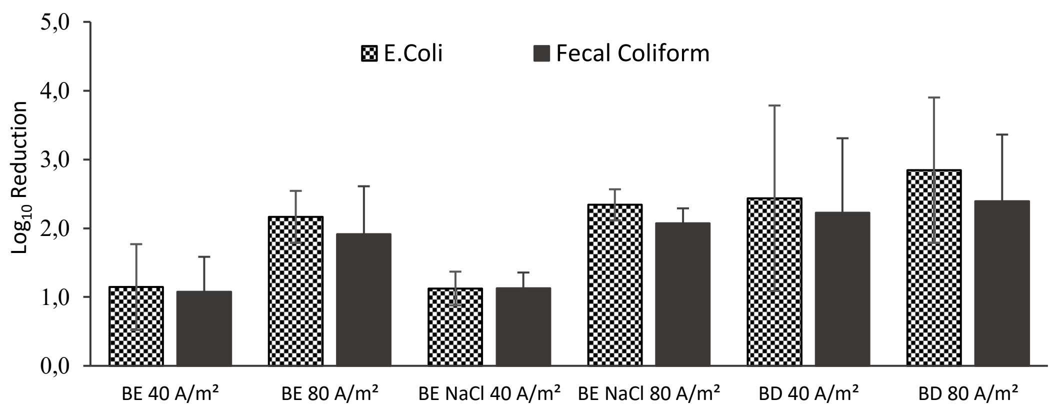

Figure 2: Microbial disinfection in the ECF process at two CD: 40 A/m^2 and 80 A/m^2. The experiments involved treating MWW BE (n=3), MWW NaCl BE (n=3), and MWW BD (n=3).

The MWW BD from Khulna exhibits higher microbial disinfection at a lower applied CD of 40 A/m^2, in comparison to the MWW BE from Kortrijk (Figure 2). The higher NaCl content in the MWW sample from Khulna, compared to the Kortrijk MWW samples (Table 1), significantly affects microbial disinfection (Figure 2). Electrolysis, in-situ anodic oxidation, and sweep coagulation are considered as the disinfection mechanisms in the ECF process (Ingelsson et al., 2020). When the CD is reduced to 40 A/m^2, there is a decrease in OPEX, i.e., 0.24 €/m^3 and 0.65€/m^3 respectively at CD 40 and 80 A/m^2 (Figure 1). However, the disinfection effectiveness is lower, failing to achieve a 2.0 log unit reduction for MWW BE (Figure 2). Furthermore, at 40 A/m^2, the Faraday efficiency for MWW BD is 70%, indicating possible electrode passivation or a higher occurrence of secondary electrooxidation.ECF reactor at CD 80 A/m^2 effectively removes tCOD>75%, TP>80%, TSS>70%, and E.coli > 100 CFU/100 ml (i.e., 2.0 log units reductions) when treating MWW BE (Directive 91/271/EEC). The ECF-treated MWW BE and MWW BD are considered suitable for irrigation due to the presence of TN. The lower removal of TN indicates that it can serve as a nutrient for crops (Figure 1). The treated MWWs (MWW BE and MWW BD) meet the agricultural reuse requirements of Europe (i.e., Regulation (EU) 2020/741), and the cooling, fisheries, and irrigation standards of Bangladesh (i.e., ECR 2023). The treated MWWs obtained standard level values for pH, EC, and DO, indicating its suitability for reclamation and reuse. These findings suggest that ECF treatment could serve as a viable MWW treatment and reuse strategy in various locations worldwide.

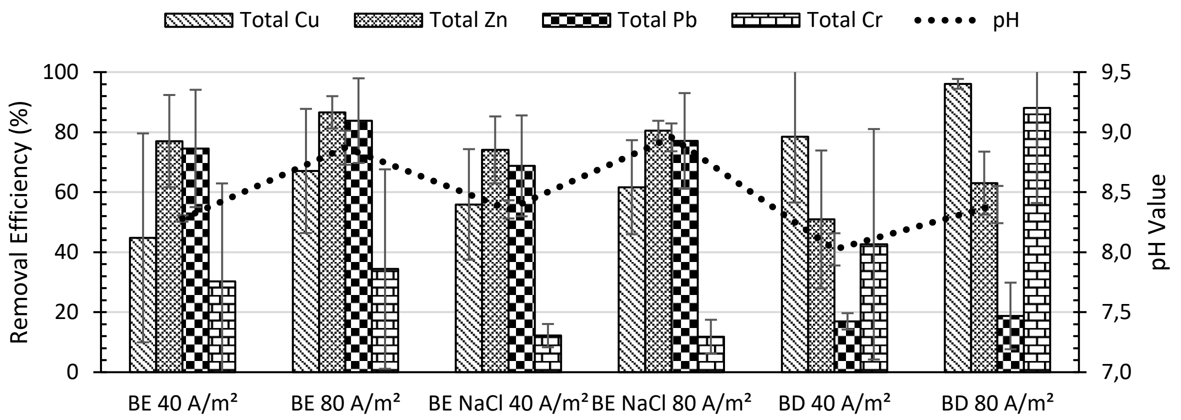

Figure 3: Heavy metal removal in the ECF process at two CD: 40 A/m^2 and 80 A/m^2. The experiments involved treating MWW BE (n=3), MWW NaCl BE (n=3), and MWW BD (n=3).

As seen in Figure 3, ECF treatment also has the potential to remove heavy metals (i.e., Cu, Pb, Zn and Cr) which is beneficial in view of (agricultural) re-use. MWW BE treated in studied ECF unit removed Zn>Pb>Cu>Cr, whereas MWW BD removed Cu>Zn>Cr>Pb (Figure 3). Higher CD enhanced heavy metal removal effectiveness in all circumstances in different pH (Figure 3). 80 A/m^2 removed more than 40 A/m^2. The hydroxide ions produced during the electrochemical reactions of the ECF treatment process increase the pH and facilitate heavy metal precipitation (Figure 3). The degree of pH increase depend on applied CD and MWW characteristics especially conductivity and alkalinity (Ingelsson et al., 2020).

Sludge management when using the ECF technology is crucial, therefore the sludge volume (Figure 4) may help select the optimal operational parameters. As demonstrated in Figure 5, a CD of 80 A/m^2 improved sludge separation by increasing flotation volume. This shows that the CD is crucial for ECF sludge separation. A higher CD increases ECF sludge dry solid (DS) concentration. ECF sludge from treating MWW collected from Harelbeke generated 0.31 ± 0.06 dm^3 biogas per / g volatile solids (VS) when applying 80 A/m². When treating MWW from Khulna (simulated with NaCl) at 40 A/m^2, 0.36 ± 0.05 dm^3 / g VS biogas was obtained. During anaerobic digestion of biologically treated sewage similar biogas production is obtained, which suggests that there are energy recovery possibilities for the ECF sludge (Hutnan et al., 2006). Furthermore, based on the sludge characteristics, it is possible to spread the sludge on agricultural land based on the Bangladesh Standards and recommendations for sludge management (2015) (data not shown). During the ECF process, successful removal of tCOD, TP, and TSS is achieved due to the characteristics of MWWs, the formation of GR, effective sludge separation through flotation and sweep coagulation. The higher NaCl content in MWW BD enhances disinfection efficacy at lower applied CD The removal of heavy metals also adds value for water reclamation purposes globally. Considering the synergistic ECF performance to treat different MWWs, this research concludes that a CD of 80 A/m^2 is ideal for resource recovery and reuse, aligning with the goals of sustainable development and the circular economy. levels. For optimal disinfection efficiency in MWW BE , and good Faraday Efficiency close to 1 in MWW BD, as well as biogas production, a CD of 80 A/m^2 is selected.

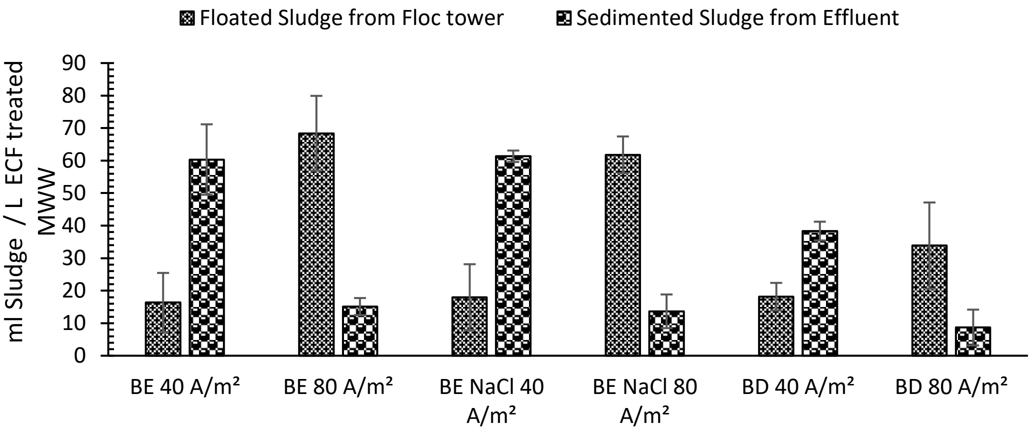

Figure 4: Sludge produced during the ECF process at two CD: 40 A/m^2 and 80 A/m^2. The experiments involved treating MWW BE (n=3), MWW NaCl BE (n=3), and MWW BD (n=3).

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References:

APHA, (1992). Standard methods for the examination of water and wastewater, 21sted. Washington, DC, New York: American Public Health Association.

Bangladesh Standards and Guidelines for Sludge Management, 2015.Department of Environment Dhaka Bangladesh. ISBN: 978-984-34-0858-7; Website: www.doe.gov.bd

EU Directive (91/271/EEC), (1991). Urban Waste Water Treatment Directive. Official Journal of the European Communities, No L135/40-52, http://data.europa.eu/eli/dir/1991/271/2014-01-01

ECR (2023). Bangladesh Environmental Conservation Rules, 2023. Bangladesh Gazette. Government of Bangladesh.

Haldar, K., Kujawa-Roeleveld, K., Dey, P., Bosu, S., Datta, D. K., & Rijnaarts, H. H. M. (2020). Spatio-temporal variations in chemical-physical water quality parameters influencing water reuse for irrigated agriculture in tropical urbanized deltas. *Science of the Total Environment*, *708*. https://doi.org/10.1016/j.scitotenv.2019.134559

Ingelsson, M., Yasri, N., & Roberts, E. P. L. (2020). Electrode passivation, faradaic efficiency, and performance enhancement strategies in electrocoagulation—a review. *Water Research*, *187*, 116433. https://doi.org/10.1016/j.watres.2020.116433

Lakho, F. H., Le, H. Q., van Kerkhove, F., Igodt, W., Depuydt, V., Desloover, J., Rousseau, D. P. L., & van Hulle, S. W. H. (2020). Water treatment and re-use at temporary events using a mobile constructed wetland and drinking water production system. *Science of the Total Environment*, *737, 139630*. https://doi.org/10.1016/j.scitotenv.2020.139630

Parmentier, D., Manhaeghe, D., Baccini, L., van Meirhaeghe, R., Rousseau, D. P. L., & van Hulle, S. (2020). A new reactor design for harvesting algae through electrocoagulation-flotation in a continuous mode. *Algal Research*, *47*, 101828. https://doi.org/10.1016/j.algal.2020.101828

REGULATION (EU) 2020/741. THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 May 2020 on minimum requirements for water reuse**.**

Schroyen M., Vervaeren H., Van Hulle S.W.H., Raes K., 2014. Impact of enzymatic pretreatment on corn stover degradation and biogas production. Bioresource Technology, http://dx.doi.org/10.1016/j.biortech.2014.09.030

Hutnan, M., Drtil, M., and Kalina, A. (2006). Anaerobic stabilisation of sludge produced during municipal wastewater treatment by electrocoagulation. *Journal of Hazardous Materials*, *131*(1–3), 163–169. https://doi.org/10.1016/j.jhazmat.2005.09.032

Sidestream sulphide-driven denitrification as robust solution to enable resource recovery in a large-scale industrial WWTP

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Keywords: energy and material recovery, large-scale industrial WWTP, innovative biogas treatment, mathematical modelling

Introduction

In recent years, the paradigm shift from wastewater treatment plant (WWTP) towards biorefineries has clearly highlighted the high potential of resources recovery, either as energy or material, from wastewater; however, the full scale implementation of novel treatment lines or more energy efficient solutions is still limited (Kehrein et al., 2020; Renfrew et al., 2022). Several emerging processes and technological solutions have been proposed in the last decades, mainly oriented to the recovery of energy, nitrogen, phosphorous and sulphur, possibly integrated with other mature technologies such as anaerobic digestion for biosolids valorisation through methane production. Among them, sulphide-driven denitrification is an appealing solution for simultaneous nitrogen (N) and sulphur (S) removal from liquid and gaseous effluents. The present work reports on a model assisted evaluation of different treatment scenarios for a large-scale industrial wastewater treatment plant, aimed at improving plant performance on material and energy recovery. The knowledge on the novel processes of S-driven denitrification gathered within previous works has been exploited to propose innovative solutions for the valorisation of the produced biosolids as well as liquid and gaseous sidestreams. Historical data on plant operation have been integrated with experimental evidence from previous works, as well as with predictive data from mathematical modelling. In accordance with plant managers' interest, special emphasis has been devoted to alternative solutions for biosolids management (from primary, secondary and tertiary sludge) and scenarios were assessed in terms of COD, N and S loads in mainstream/sidestream, process stability, effluent quality and residual biosolids waste generation. This analysis wraps up a long work conducted through experimental activities and mathematical modelling on autotrophic denitrification and on the specific WWTP, used as a case study.

Material and methods

The large-scale tannery WWTP managed by Consorzio Cuoiodepur SpA (Pisa, Italy) has been selected as a case-study. In average, the plant treats 4200 $m^3\ d^{-1}$ of industrial wastewater from the Tuscany vegetable tannery industrial district and 4000 $m^3\ d^{-1}$ of domestic wastewater from the surrounding area; yet, around 95% of pollutant load is related to the industrial influent. Tannery wastewater is characterised by high content in particulate organic matter, N and S compounds as well as tannins. The current plant configuration is represented in the reference scenario, Scenario 0, and comprises primary, secondary (conventional activated sludge) and tertiary treatments (fig. 1); sludge treatment comprises dewatering and thermal dehydration. Sidestreams supernatants originated in thickening and dewatering are recirculated back to the mainstream. Dehydrated sludge is partially disposed and partially mixed with other tannery industry residues to meet proper C/N/P content for fertilizers standards. Two novel scenarios have been simulated with the purpose of increasing plant resource valorisation and resource circularity, both including anaerobic digestion for sludge valorisation. In Scenario 1, sidestreams generated by digestate dewatering are recirculated back to the mainstream and sulphide removal in biogas is accomplished through an aerobic bioscrubber achieving elemental sulphur recovery (fig. 2a). In Scenario 2, liquid sidestreams are treated in a dedicated line where partial nitrification, operated as complete nitritation, is coupled with sulphide-driven autotrophic denitrification for the removal of ammonia from the side stream and sulphide from the biogas (fig. 2b); from a technological point of view, an anoxic bioscrubber is selected as suitable solution. The software SUMO22 (Dynamita, Canada) was adopted as simulation environment. The library model Sumo2S, comprising the sulphur bio-chemical cycle, was selected and two main modifications were implemented: i. biological sulphur oxidation model was adapted according to the experimental evidences and mathematical modelling in previous study (Polizzi et al., 2022b; Valdes et al., 2023); ii. two new processes were included for the conversion of particulate unbiodegradable COD and inorganic solids as presented in Polizzi et al. (2022a). The model on Scenario 0 was calibrated on the new data set on year 2022, on influent characteristics and operational conditions, and parameters on the novel units were estimated, when needed. The average value for SRT (50 d) and DO concentration in the mainstream nitrification tank were maintained the same in all the scenarios (i.e. no further optimization was performed). The main outcomes are derived from steady-state simulations but dynamic modelling has been performed in order to explore process stability in Scenario 2. The comparative evaluation of the three scenarios was based on mass balance and mass flow analysis.

Results and discussion

Figure 1 shows the model representation of Scenario 0. The model of the biological unit was calibrated and validated in previous studies (Polizzi et al., 2022a) and model boundaries have been extended in the present work to include the whole water and sludge lines (previous model boundaries are graphically indicated in fig. 1). Tertiary settler was not included in the model but tertiary sludge was added as an external influent of the thickener unit.

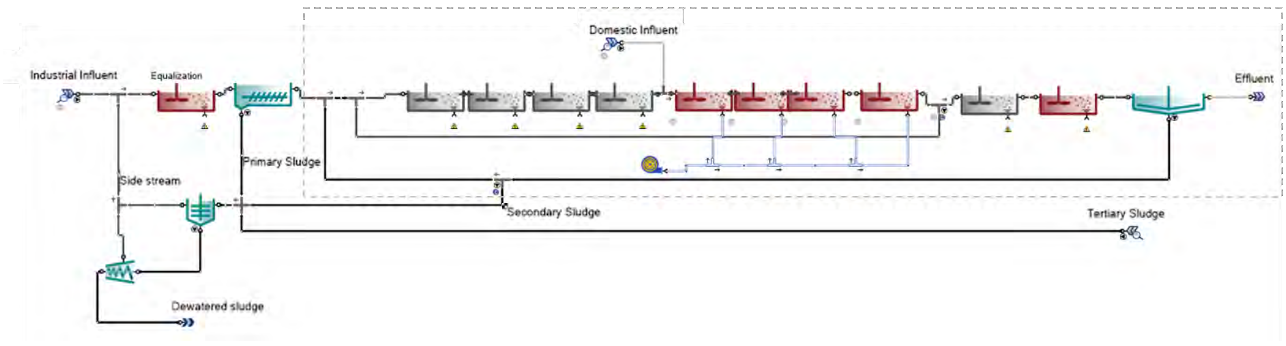

Figure 6 Scenario 0 (reference scenario). Model representation in SUMO22. Dotted grey rectangle represents model boundaries of previous modelling work.

As presented in table 1, the model met effluent quality, in terms of average COD and N compounds concentrations, as well as VSS concentration in the biological unit. The high COD concentration in the secondary effluent, around 600 mg L^{-1}, is due to the high content of bio-refractory tannins, removed in the subsequent tertiary treatment. The modelled biosolids exiting the dewatering unit are around 22 tonVSS d^{-1} versus an average value of 21±2 tonVSS d^{-1}, primary sludge accounting for more than 60% of the produced solids.

Table 2 Main outcomes of Scenario 0, observed vs modelled data.

Parameter	Observed value	Modelled value
Secondary Effluent soluble COD (mg O_2 L^{-1})	581±177	579
Secondary Effluent Ammonia (mgN-NH_4^+ L^{-1})	0.3±0.1	0.2
Secondary Effluent Nitrate (mgN-NO_3^- L^{-1})	11±2	12.3
MLVSS in mainstream biological unit (mgVSS L^{-1})	8381±1330	7404

In figure 2a and 2b, the modelled Scenario 1 and 2 are presented. The H_2S load to be removed from the biogas has been estimated through sulfur balance in the anaerobic digestion unit and added as a fictitious influent representing the effluent of the absorption tower in a bioscrubber. In these scenarios, an average load of 400 kgS-HS^- d^{-1} has been estimated and applied in both scenarios.

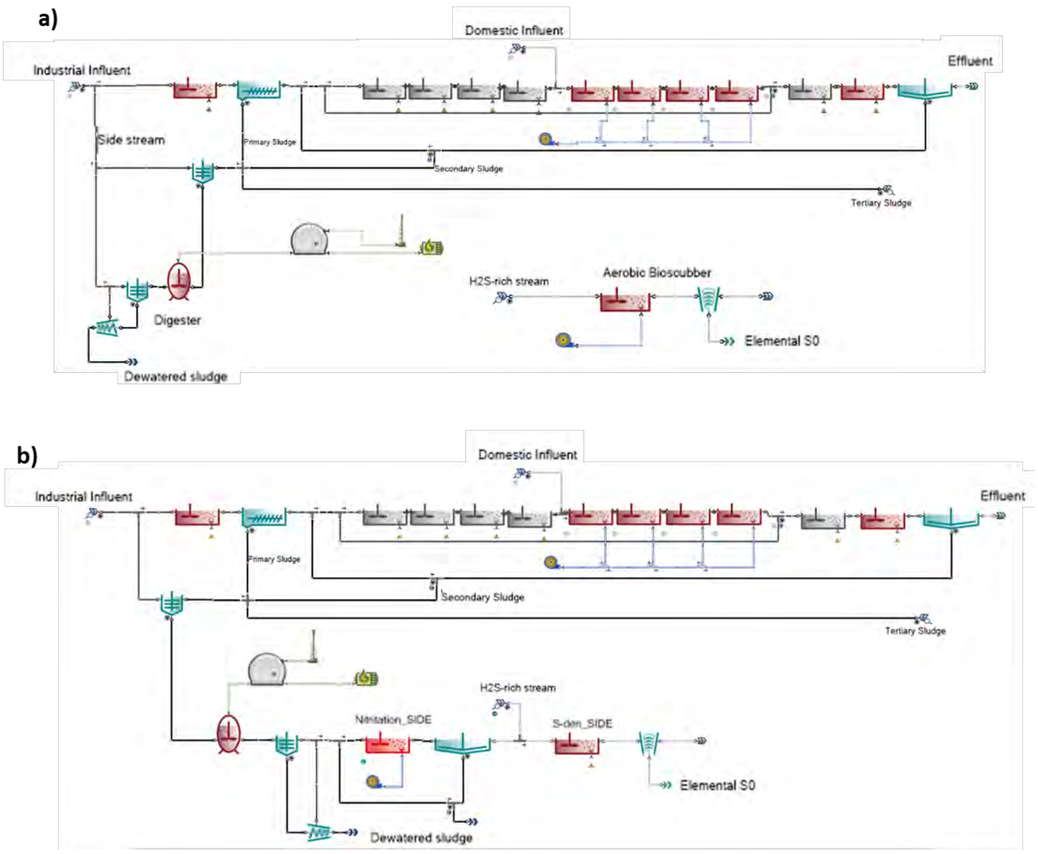

Figure 7 Model representations in SUMO22 of Scenario 1 (a) and Scenario 2 (b).

Model results show that anaerobic digestion of tannery sludge allows for significant methane production, i.e. potential energy recovery, both in scenario 1 and 2. A specific methane production (SMP) of 0.31±0.01 NmL $gVSS_{in}^{-1}$ is predicted, resulting in a biogas production of 11500 and 11300 $Nm^3\ d^{-1}$ for Scenario 1 and 2, respectively, with CH_4 content of 62-63% in both cases. This data is considered conservative since experimental data from previous works showed a higher SMP of 0.35 NmL $gVSS_{in}^{-}$, at optimised conditions (data not shown). As a direct consequence, volatile solids to be disposed are reduced by 54% and 59% in Scenario 1 and 2, respectively, which constitutes a direct environmental advantage since it allows for a significant saving of methane, currently used for sludge dehydration. The impact of variations in loads of biodegradable COD and ammonia recirculated in the sidestreams and eventually treated in the mainstream biological unit was evaluated in a comparative analysis, together with S load from biogas treatment and overall biosolids production. Comparative results are summarized in figure 3. In Scenario 1, sidestream determine a 16% increase of the overall ammonia and organic N load in the mainstream oxidation and a concomitant 5% reduction of the bCOD load, whereas in Scenario 2, the avoided sidestream recirculation results in 6% and 7% reduction for bCOD and N load in the mainstream. Regarding effluent quality, both alternative scenarios are able to achieve complete nitrification (NH_4^+ < 0.3 mgN L^{-1}) but the higher N load in Scenario 1 would require higher recirculation flowrates (i.e. higher energy demand for recirculation pumps) to meet effluent standard on nitrate, while the lower N load in Scenario 2 allows for a reduction of effluent nitrate (compared to current levels), down to 7 mgN L^{-1}. In light of these performances, Scenario 2 is indicated as the most appealing in terms of energy efficiency and resource recovery. To address plant managers' need of novel process reliability, dynamic modelling has been performed in Scenario 2 to simulate a wide range of S/N ratio in the sidestream that can be encountered in real-scale operation, possibly with sudden variations. As presented in our previous studies, the S/N that can be handled by S-driven denitrification systems is very wide, provided that the oxidized/reduced forms of the products can vary according to the S/N applied (Valdes et al., 2023). Dynamic simulation results show that the coupled system of nitritation and autotrophic denitrification shows high stability in achieving sulphide and nitrite removal in wide range of S/N ratios (1.3-2.3 gS gN^{-1}); the main difference relies in the production of SO_4^{2-} or S^0 as end-product and S^0 recovery (from 11 to 53%), offering a reliable solution in terms of gaseous and liquid effluents quality.

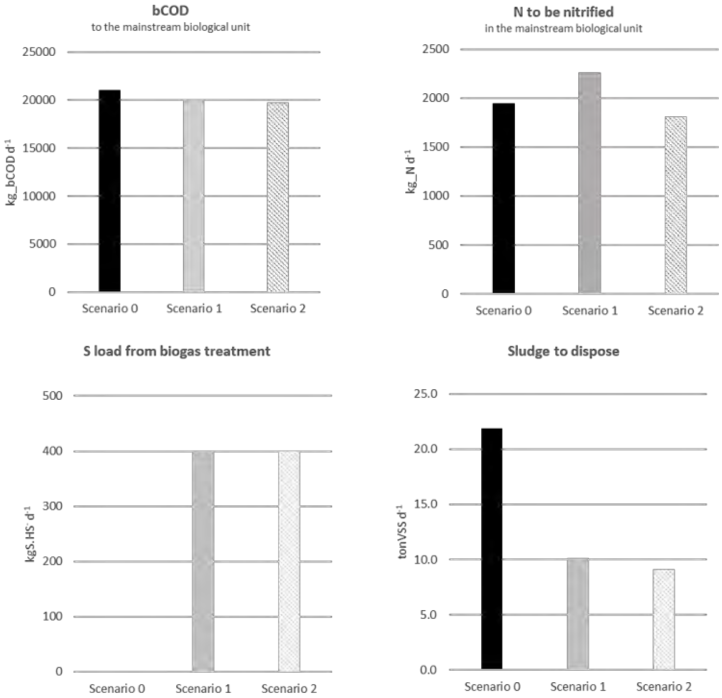

Figure 8 Comparison of C, N, S loads as well as energy demand and solids production, in the 3 scenarios.

The critical comparison of innovative scenarios of a large-scale WWTP through mass flow analysis reported in the present work is intended to provide process engineers with valuable information for the implementation of process upgrading towards resource recovery. In this perspective, S-driven denitrification shows to be a robust innovative solution for sidestream and biogas treatment.

Acknowledgements

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References

Kehrein, P., Van Loosdrecht, M., Osseweijer, P., Posada, J., 2020. Exploring resource recovery potentials for the aerobic granular sludge process by mass and energy balances-energy, biopolymer and phosphorous recovery from municipal wastewater. Environ. Sci. Water Res. Technol. 6, 2164–2179. https://doi.org/10.1039/d0ew00310g

Polizzi, C., Falcioni, S., Mannucci, A., Mori, G., Nardi, A., Spennati, F., Munz, G., 2022a. Integrating online differential titrimetry and dynamic modelling as innovative energy saving strategy in a large industrial WWTP. Clean Technol. Environ. Policy 24, 1771–1780. https://doi.org/10.1007/s10098-022-02285-2

Polizzi, C., Gabriel, D., Munz, G., 2022b. Successful sulphide-driven partial denitrification : Efficiency , stability and resilience in SRT-controlled conditions ☆. Chemosphere 295, 133936. https://doi.org/10.1016/j.chemosphere.2022.133936

Renfrew, D., Vasilaki, V., McLeod, A., Lake, A., Danishvar, S., Katsou, E., 2022. Where is the greatest potential for resource recovery in wastewater treatment plants? Water Res. 220, 118673. https://doi.org/10.1016/j.watres.2022.118673

Valdes, E., Gabriel, D., Gonzalez, D., Munz, G., Polizzi, C., 2023. Integrating thermodynamics and mathematical modelling to investigate the stoichiometry and kinetics of Sulphide Oxidation-Nitrate Reduction with a special focus on partial autotrophic denitrification Available.

Recovery of resources and generation of valuable products from municipal wastewater – assessment of products quality

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Keywords: Circular economy, wastewater, resource recovery, quality control, contaminants

ABSTRACT

Background

Current linear economy is not sustainable and needs to transition to a circular economy to utilize resources as long as possible and minimize environmental impacts. The transition from the linear economic model to the circular economy in the water sectors requires rethinking the current wastewater treatment paradigm. In the water sector, transition to the circular economy focuses on promoting the reuse, recycling, restoration, and recovery of water resources. Wastewater should no longer be regarded as a waste, but as a pool of resources with the potential to recover and generate valuable products such as reusable water, nutrients, biopolymers, biofuels, thermal energy, etc. Furthermore, to support the transition, the term "wastewater treatment plant" should be replaced by "water resource recovery facility" (Krzeminski & Vogelsang, 2021).

As part of the proposed revision of the urban wastewater treatment directive (UWWTD), the European Commission recommends defining minimum recovery rates of nutrients, including the critical substance phosphorous, from the sludge at the EU level to support circular economy (EC, 2022). Yet, the recovery and reuse bring about new challenges and concerns related to the quality of the products, including water (Rey-Martínez et al., 2022; Krzeminski et al., 2019). A key barrier for implementing circular economy systems in the urban water sector and closing the water loops is the inherent risk to health and safety associated with using materials recovered from sources that may contain toxic chemicals and pathogens (Kehrein et al. 2020).

Objectives

The objective of this study is to determine the composition and levels of impurities and hazardous substances in resources recovered from different streams at wastewater treatment plants (WWTPs). The assessed resources will include organics, biopolymers, nitrogen- and phosphorus-based materials, and water. The observed levels together with appropriate safety factors will indicate whether the resources can be used directly as final products or if further upstream or downstream measures need to be implemented.

Materials & Methods

The work is being carried out as part of the SIREN project which exemplifies research on simultaneous recovery of energy, organics and nutrients and generation of valuable products from municipal wastewater (Figure 1). It also highlights that recovery and reuse brings about new challenges and concerns related to the quality of the products, including water.

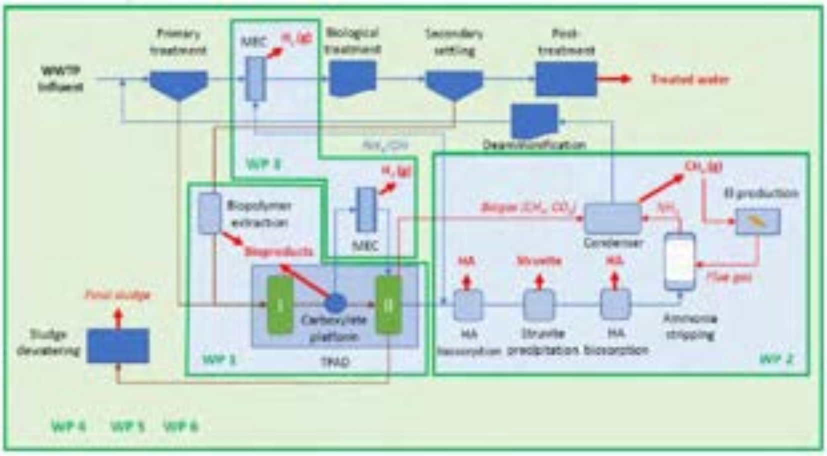

Figure 1. Project boundry and scope, with points of recovery of the different materials.

The recovered materials include humic acids, alginate-like exopolysaccharides, struvite, all in solid state, and water which were recovered from the different streams at full-scale municipal WWTPs as provided in Table 1.

Table 1. List of the materials recovered and their origin / point of recovery.

Type of material	Material	Source / Point of recovery
Organics	Humic acids	Sludge line reject water
Biopolymers	Alginate	Waste activated sludge
Nitrogen-products	Ammonium carbonate	Sludge line reject water
Phosphorous-product	Struvite	Sludge line reject water
Water	Water	WWTP effluent

Depending on the intended applications, the recovered materials will be analysed by a battery of analytical tools to determine main components and levels of the impurities, regulated hazardous compounds and non-regulated hazardous compounds. To this end, the levels of nutrients (carbon, nitrogen, phosphorous), macromolecules (e.g., Ca, Mg, Na), chlorine, and metals (e.g., Fe, Mn, Ni, Cu, Zn, Cd, Pb, Hg, Al, As) will be determined. The levels of the selected industrial chemicals such as polycyclic aromatic hydrocarbons (PAHs), phthalates (e.g., DBP, DPP, DEHP), musk compounds (e.g., galaxolide, tonalide), PFAS and total organic fluorine (TOF), will be quantified. In addition, the content of the microplastic, 12 antibiotic resistance genes and selected pharmaceuticals including ones on the revised urban wastewater treatment directive list (e.g., carbamazepine, clarithromycin, diclofenac) is planned to be quantified. The full list of analyses carried out at research (NIVA, NILU) and commercial laboratories (ALS, Resistomap) will be shared during the presentation.

Results & Discussion

The criteria used to define the appropriate analyses for each of the materials recovered will be presented and discussed. This includes, i) existing relevant European regulation such as the European Fertilizer regulation and Sewage Sludge Directive, ii) potential upcoming European regulation such as proposed UWWTD revision and evaluation of Sewage Sludge Directive, iii) extensive sewage sludge monitoring programs in Norway and Sweden, iv) information gathered for similar commercial products on the market.

We will present an initial quality assessment of the characterized recovered resources and compare with the literature data. During the presentation, the levels of the selected quality parameters for the different materials/resources will be presented highlighting the compliance with the regulatory requirements. We will discuss the potential shortcomings, barriers, and opportunities for application-specific utilization of the recovered resources from municipal wastewaters.

It is expected that the work presented will drive further research in the area, provide relevant information for both researchers and practitioners. The outcomes of the quality assessment will contribute to overcoming implementation barriers and enhancing reusability potential of the value-added recovery products contributing to the circular economy transition in the water sector.

Acknowledgements

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References:

EC, 2022. Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL concerning urban wastewater treatment (recast), COM/2022/541 final, https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52022PC0541

Krzeminski, P., Tomei, M.C., Karaolia, P., Langenhoff, A., Almeida M.C., Felis, E., Gritten, F., Andersen, H.R., Fernandes, T., Manaia, C.M., Rizzo, L., Fatta-Kassinos, D. (2019) Performance of secondary wastewater treatment methods for the removal of contaminants of emerging concern implicated in crop uptake and antibiotic resistance spread: A review, Science of the Total Environment 648C, pp. 1052-1081

Rey-Martínez, N., Guisasola, A., Baeza, J.A. (2022) Assessment of the significance of heavy metals, pesticides and other contaminants in recovered products from water resource recovery facilities, Resources, Conservation and Recycling 182, 106313.

Kehrein, P., van Loosdrecht, m:, Osseweijer, P., Garfí, M., Dewulf, J., Posada J. (2020) A critical review of resource recovery from municipal wastewater treatment plants – market supply potentials, technologies and bottlenecks, Environmental Science: Water Research & Technology 6, 877-910

Gull i kloakken: Begrepet «avløpsrenseanlegg» er avleggs og bør skrotes, Pawel Krzeminski, Christian Vogelsang, Forskersonen and Biogassbransje, 2021. https://forskersonen.no/baerekraft-energi-kronikk/gull-i-kloakken-begrepet-avlopsrenseanlegg-er-avleggs-og-bor-skrotes/1879112

Session A4: Novel designs of Constructed Wetlands

The Integrated Constructed Wetlands: A review

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Keywords: Integrated, Wetlands, Sequestration, Biodiversity, Sustainability, Landscape.

ABSTRACT

The Integrated Constructed Wetland (ICW) concept is based upon inextricipaly linking water treatment within its landscape setting and enhanced biodiversity. The concept evolved initially from the necessity to improve water quality in drainage channels from intensive farming practice 35 years ago (Harrington and Ryder, 2002; Harrington *et al*., 2005). It was inspired by ecosystem studies conducted at the US Forest Service's 3,160 ha, Hubbard Brook Ecosystem/Catchment Study Area.

Given that typical land use was to be reallocated to treat water, the Vitruvian principles of *firmitas*, *utilitas*, and *venustas* ("strength", "utility", and "beauty") were seen as appropriate to the concept and design approach. Social, economic, and environmental elements were considered inextricably linked to optimise land and water use. Lands of appropriate area, topography, and hydraulic soil impedance capable of supporting helophyte vegetation were fundamental to their construction and function. The sustainable use of land towards intercepting polluted water from farms was seen as both a novel alternative land use and a challenge to the typical practice of interception/collection/storage and subsequent overland dispersal.

An ICW design is a land/water ecosystem-based approach that is typically, though not exclusively, best suited to rural situations. There are numerous successful applications demonstrated in a wide range of municipal sewage (Figure 1), agriculturally-derived wastewaters, liquid livestock manures, landfill leachates and various mine and quarry waters (Carty and Harrington, 2017; Harrington and Scholz, 2010). Their treatment performance across all parameters measured has been demonstrated to be exemplary, including those of emerging pollutants and microbial pathogenicity.

The concept necessitates a bespoke approach to each site where it is applied, integrating all associated water management needs within its immediate, and wider, landscape setting. It facilitates the biodiversity of adjacent areas with consequential advancement in social and economic gains. The bio-geo-chemical processes operating in and associated with ICWs are fundamentally similar to those found in conventional wastewater treatment systems: microbial decomposition of influent content and nutrient degradation and precipitation/retention.

The ICW concept's ecosystem-based approach derives its benefits from optimising the linkages of water management with that of appropriately scaled landscape-fit and biodiversity. Water quality of the associated through-flow is optimally achieved sequentially through a series of interlinked densely helophyte (emergent) vegetated shallow water bodies of sufficient area and optimal configuration. They are designed to self-adjust to both weather related flow events, including the challenges from heavy rainfall and flooding, and periods of drought.

The ICW concept grew from previous studies in functional ecosystem biology and their associated geology, hydrology and landscape settings (Scholz et al., 2007, Harrington *et al*., 2007). The various studies undertaken on ICW performance identify their wide range of applicability, including the biogeochemical factors that determine their success. Their application furthermore exemplifies the benefits of the joined-up 'Ecosystem Approach' advocated by the UNEP, above. These include a range of ancillary environmental, social and economic benefits that are increasingly valued. These 12 principles apply to within, adjacent and the wider social and economic contexts (Harrington et al., 2011). ICW systems continue to be applied and further developed by the authors at VESI Environmental Ltd. and their associates. They include current projects for UK water agencies, Irish state water utility (Uisce Éireann), along with a wide range of private and corporate entities in Ireland.

Rather than being primarily supported by electro-mechanical technological infrastructure and associated energy demands, the ICW 'ecosystem-based approach' uses hydraulic flow within and between the

segmented earth-bunded wetland areas (Everard *et al*., 2012). These are sized and configured within the constraints of availability/suitability and the quality of outflow required. Treatment is incrementally achieved as the through-flowing water is subject to contact with the biological micro-films in and on the helophyte vegetation and its accumulating detritus. The water depth of the helophyte vegetated retention areas must be for their growth and appropriately configured, i.e. supporting dense emergent vegetation and supporting complex biofilms that deliver treatment. Locally derived soils within available sites are worked to the necessary hydraulic resistance to ex-filtration. ICWs are essentially a land/water ecosystem based exercise. Though similar in some ways to 'reed bed systems' they are more ecologically comprehensive with diverse biological structure through all seasons.

Microbial communities within and associated with the helophyte vegetation and its soil media are complex, comprising prokaryotic and eukaryotic bacteria, fungi, yeasts and protozoa, and associated invertebrates/vertebrates (Beccera-Jurado *et al*., 2010). They provide the basis for the complex processes for both inorganic retention and organic decomposition. Associated flow management towards achieving the necessary retention is achieved by providing the inflow and through-flow (flow distribution) with sufficient vegetated area with optimal configuration. The multiple design benefits accruing from ICW systems have been tentatively demonstrated to capture and store carbon with traded credits of about 5t /h/y based upon organic matter accretion.

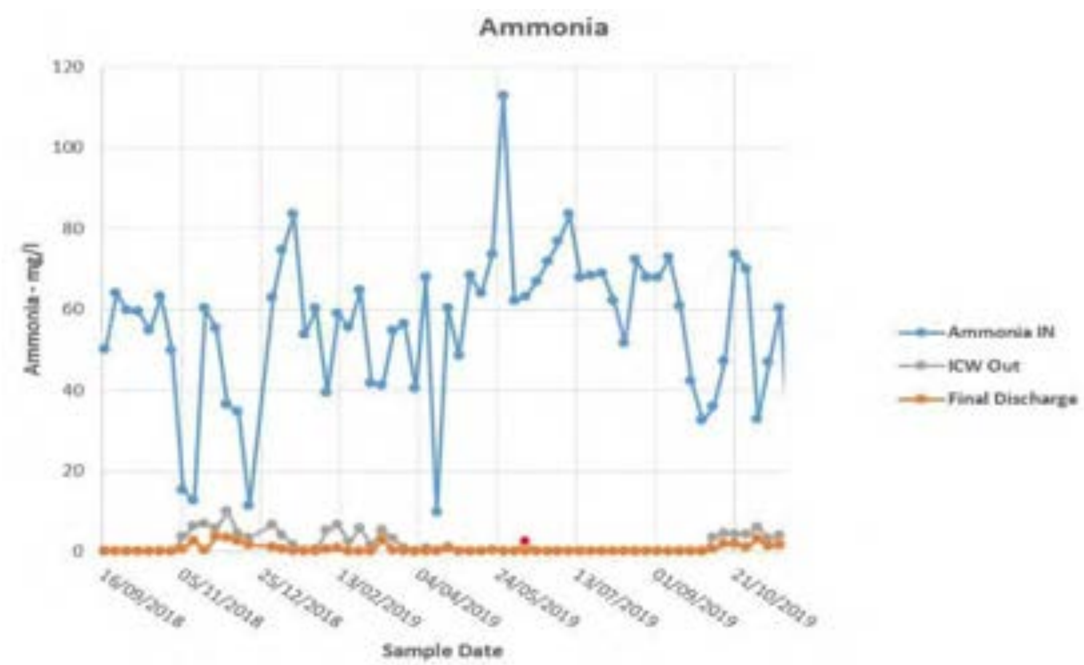

Fig 1. Ammonia reduction performance in municipal ICW

The land cost for ICWs is generally less than the costs associated of conventional electrical-mechanical systems used in the treatment of municipal sewage, though this may be prohibited in urban areas. For agricultural farm stock/waste water the foregone costs associated with storage and land spreading are generally greater than that of land value and construction. Similarly for mining and stone quarrying, water treatment has been less when ICW systems are installed.

As the ICW concept derives its benefits from optimising the linkages of water management with that of landscape-fit and biodiversity, attention to these two additional considerations is essential. By so doing key economic, social and wider environmental benefits accrue. Their benefits are across many necessities for a more 'Sustainable World' advocated by national and international institutions. They include in the first instance water quality with economic benefits to all associated: customers, shareholders (public, corporate or private), ancillary land use benefits, and ecologically dependent species.

The ICW concept has been demonstrated to provide secure high level treatment for a diversity of polluted water sources with capacities addressing the needs of advanced circular economies, support for biodiversity and advancement of appreciation/awareness of nature generally.

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Uisce Éireann

Monaghan County Council

Kerry County Council

References:

Carty, A. and Harrington, C., 2017, May. B4-Integrated constructed wetlands for mine-influenced water. In *ABSTRACT BOOK* (p. 139).

Everard, M., Harrington, R. and McInnes, R.J., 2012. Facilitating implementation of landscape-scale water management: The integrated constructed wetland concept. *Ecosystem Services*, *2*, pp.27-37.

Becerra-Jurado, G., Harrington, R. and Kelly-Quinn, M., 2012. A review of the potential of surface flow constructed wetlands to enhance macroinvertebrate diversity in agricultural landscapes with particular reference to Integrated Constructed Wetlands (ICWs). *Hydrobiologia*, *692*, pp.121-130.

Harrington, R., Carroll, P., Cook, S., Harrington, C., Scholz, M. and McInnes, R.J., 2011. Integrated constructed wetlands: water management as a land-use issue, implementing the 'Ecosystem Approach'. *Water Science and Technology*, *63*(12), pp.2929-2937.

Harrington, C. and Scholz, M., 2010. Assessment of pre-digested piggery wastewater treatment operations with surface flow integrated constructed wetland systems. *Bioresource technology*, *101*(20), pp.7713-7723.

Scholz, M., Harrington, R., Carroll, P. and Mustafa, A., 2007. The integrated constructed wetlands (ICW) concept. *Wetlands*, *27*(2), pp.337-354.

Harrington, R., Carroll, P., Carty, A.H., Keohane, J. and Ryder, C., 2007. Integrated constructed wetlands: concept, design, site evaluation and performance. *International Journal of Water*, *3*(3), pp.243-256.

Harrington, R., Dunne, E.J., Carroll, P., Keohane, J. and Ryder, C., 2005. The concept, design and performance of integrated constructed wetlands for the treatment of farmyard dirty water. *Nutrient management in agricultural watersheds: a wetlands solution. Wageningen Academic Publishers, Wageningen*, pp.179-188.

Harrington R and C Ryder (2002) The use of Integrated Constructed Wetlands (ICWs) in the Management of Farmyard Runoff and Waste Water. National Hydrology Seminar 2002: Water Resource and Management Sustainable Supply and Demand. Irish Nat. Committees of IHP and ICID. *The Institution of Engineers of Ireland* 55-63.

Efficiency removal of specific substances in multistage treatment wetland for urban drainage water

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Keywords: microplastic; polyaromatic hydrocarbons; multistage treatment wetlands; urban stormwater pollution

ABSTRACT

INTRODUCTION

According to the latest IPCC report (2021), climate models estimate that the number of extreme weather events, such as more frequent and more intense precipitation periods during the summer, will increase and that winters will become wetter and milder. The changing precipitation patterns have already caused flesh floods in cities, as well as uncontrolled spills of uncleaned drained water to natural recipients as the existing sewage network does not have the appropriate capacity. Progressive urban development even deeper affects the environmental balance and disrupts the hydrological cycle in which rainfall plays a significant role. Recent trends in water management include stormwater in the Integrated urban water cycle as one of the water resources for different urban purposes (Oral et al, 2020, Langergraber et al., 2021). However, stormwater runoff from urban areas contains numerous (also toxic) substances that are on the list of priority substances like heavy metals or polyaromatic hydrocarbons (PAH) according to Directive 2000/60/EC, and new emerging pollutants like microplastic which are not targeted by any directive or regulation so far. Their presence and quality depend on many factors among others type of the catchment and frequency of rain events. Since stormwater is considered a valuable resource for the environment, many technical solutions are implemented that enable effective stormwater management for potential reuse in the urban water cycle. The study aimed to test the hybrid constructed wetland as a technology for the treatment of urban derange discharge and the potential reuse of treated water for watering urban greenery. In the study, the priority substance like heavy metals and PAHs and emerging pollutants like microplastic have been analysed. As well as screening tests for microbiological properties (*Escherichia coli and Enterococcus)* have been done.

METHODS

In this study, a multistage constructed wetland (MCW) pilot installation was used to remove selected groups of priority substances and emerging pollutants from a drainage collector in Gdańsk, Poland.

Collector water is a mixture of the former stream (closed in the underground pipe now), drainage water, and stormwater from the urban district of Gdańsk. The investigation has been carried out over two years period in an outdoor technical pilot installation consisting of 5 stages of treatment. The MCW was discharged by various hydraulic loads to mimic storm events. The flow in the MCW varied from 212 to 710 L/d. The test samples were taken directly from the retention tank of the Kołobrzeska collector and after the treatment process as well as after each stage of treatment in a multistage treatment wetland (Fig.1). Heavy metals such as zinc, cadmium, copper, nickel, and lead were determined by inductively coupled plasma optical emission spectrometry (ICP-OES), while mercury was determined by atomic absorption spectrometry (AAS). The HPLC-FLD/UV method, i.e., high-performance liquid chromatography with fluorescence/spectrophotometric detection, was used to determine polycyclic aromatic hydrocarbons. Samples for the presence of microplastics were collected using the UFO (Universal Filtering Object) device and ,the following methods were used to determine microplastics:

(1) in the particle range of 10–500 µm—the micro-Fourier transform infrared spectroscopy method (FPA-_FT-IR);
(2) for particles larger than 500 µm—total weakened infrared spectroscopy (ATR-FTIR).

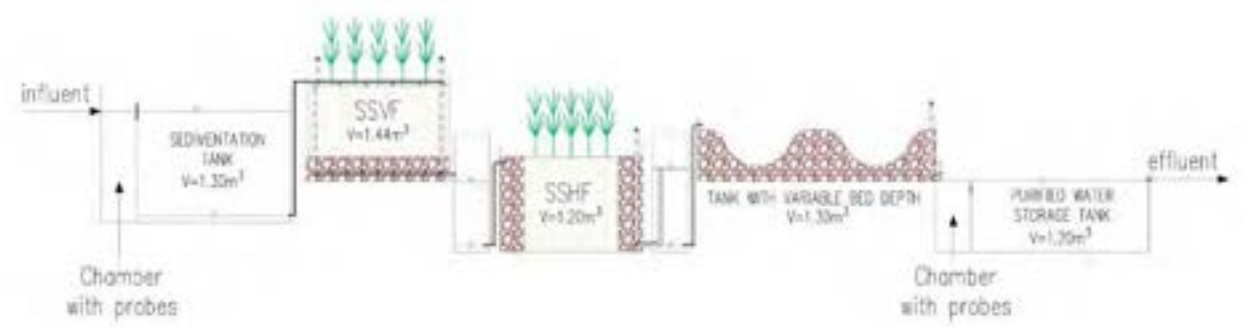

Fig. 1. Technological scheme of the MTWs. 1. Sedimentation tank, 2. 1st stage bed with the subsurface vertical flow (SSVF), 3. 2nd stage bed with the subsurface horizontal flow (SSHF), 4. reservoir with variable bed depth, 5. purified water storage tank; S1 and S2—water-collecting wells after SSVF and SSHF beds (Jakubowicz et al., 2022)

RESULTS

As shown in Fig. 2, the concentration of Enterococcus in the inflow to the facility was much higher than the concentration of Escherichia coli. According to the literature, both groups of bacteria generally constitute the main share of pathogenic microorganisms in surface runoff, but Enterococcus are becoming more and more widespread (Díaz et al., 2010; Moore et al., 2008).

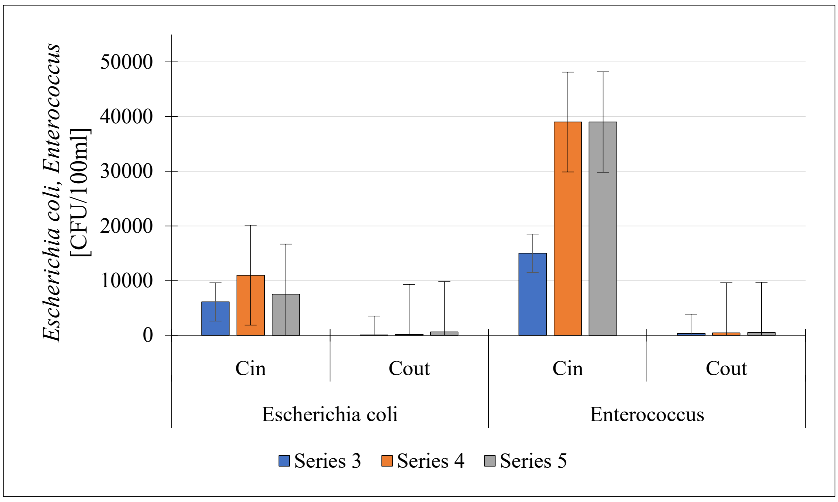

Fig. 2 Concentrations of *Escherichia coli* and *Enterococcus* bacteria, in the inflow and outflow in MTW, C_{in} - concentration in the inflow, C_{out} - concentration in the outflow

The results obtained in this study for MTW, Escherichia coli from 91.7 to 99.9%, and Enterococcus from 97.7 to 98.9%, respectively, revealed a high removal efficiency and are consistent with the results of other authors at a very high level, comparable to that reported in the literature (Díaz et al., 2010; Moore et al., 2008).

In MTW, a high PAH removal efficiency was observed, ranging from 65 to 100%, but in the vast majority of cases this efficiency was close to 100% (Fig. 3). In the measurement series no. 5, the removal efficiency of phenanthrene, fluoranthene, fluorene, and pyrene was 65%, 90%, 61%, and 88%, respectively, and low molecular weight - therefore, the obtained values of removal of these PAHs in the range of 65-90% are a good result.

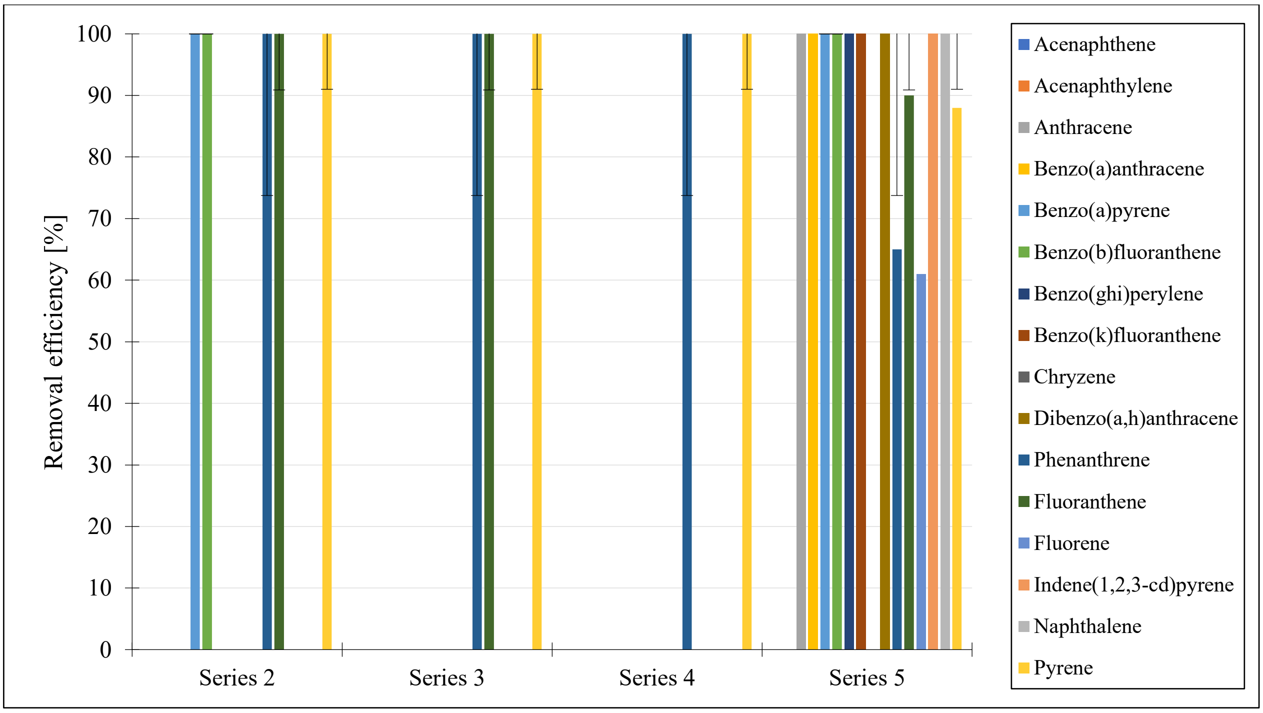

Fig 3. Efficiency of PAH removal in four measurement series

This study presents the preliminary research results related to the detection of microplastics and the effectiveness of their removal in a multistage wetland system (Fig.4).

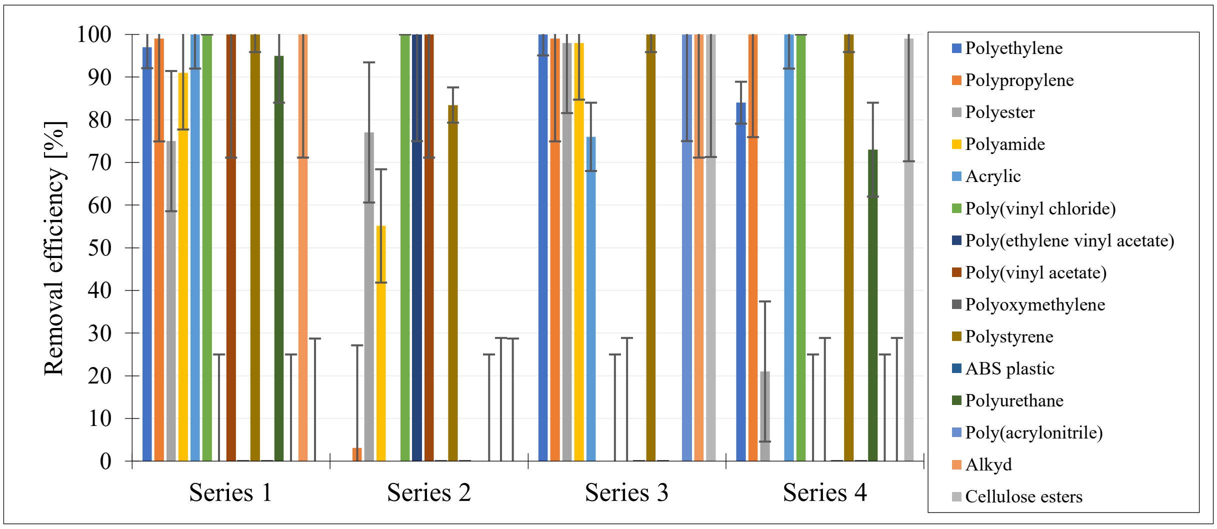

Fig 4. Efficiency of various microplastics (MPs) removal in four measurement series

Selected results of MPs determinations are presented in Fig. 4, which concern only substances detected in rainwater at the Kołobrzeska collector, including polyethylene (PE), polypropylene (PP), polyester, polyamide (PA), acrylic, polyvinyl chloride (PVC), polystyrene (PS), polyurethane (PU) and alkyd. The occurrence of natural polymers such as cellulose and proteins (biopolymers) was not taken into account in further analyses. The MPs removal efficiency in the MTW was 93% in the first measurement series, 0.01% in the second measurement series, 89% in the third measurement series, and 66% in the fourth measurement series, respectively. Comparable research results were also observed in other research centers, where the efficiency of microplastic removal in wetlands was in a very wide range, ranging from -27% to 100% (Chen et al., 2021, Zhou et. al., 2022, Long et al., 2023,). The highest efficiency, ranging from 89.3 to 100%, was obtained in hybrid facilities, consisting of a bed with a subsurface flow (vertical or horizontal) and a bed with a free water table. On the other hand, low efficiency was obtained in units operating individually, i.e. as single-stage systems, especially in the case of beds with a free mirror, where negative indices were achieved. Subsurface

flow beds, due to the filling acting as a filter, play a decisive role in the processes of sedimentation, filtration, and sorption, which cause temporary or permanent retention of microplastic particles.
Depending on the hydraulic load of the bed, the reduction efficiency ranged from 26.19% to 100% for heavy metals (while the most optimal conditions were observed for the hydraulic load of 75.43 mmd^{-1}), from 77.16 to 100% for microplastics, and reached 100% for polycyclic aromatic hydrocarbons. An increase in Zn, Cu, and Pb concentrations was also observed after the purification process, which may be caused by the phenomenon of suffosion, i.e., the washing out of these elements from the substrate of the beds.

CONCLUSIONS

Obtained results showed that collector water was characterized by variable concentrations of heavy metals (Zn, Cd, Cu, Ni, Pb, Hg), polycyclic aromatic hydrocarbons (PAHs) like benzo(a)pyrene, benzo(b)fluoranthene, phenanthrene, fluoranthene, and pyrene and microplastics. The efficiency of total suspended solids (TSS) was very high and varied from 94% to 100% and surprisingly was higher for higher hydraulic loads.

Depending on the hydraulic load of the first bed (SSVF), the reduction efficiency for heavy metals ranged from 26.19 to 100%, for microplastics from 77.16 to 100%, while for PAHs it was consistently high and equal to 100%.

MTW could also ensure the high removal of pathogens like bacteria of *Escherichia coli* and *Enterococcus* type.

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References

IPCC. Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change; Pörtner, H.-O., Roberts, D.C., Tignor, M., Poloczanska, E.S., Mintenbeck, K., Alegría, A., Craig, M., Langsdorf, S., Löschke, S., Möller, V., et al., Eds.; Cambridge University Press: Cambridge, UK,2022

Chen Y, Li T., Hu H., Ao H., Xiong X, Shi H., Wu C.,(2021) Transport and fate of microplastics in constructed wetlands: A microcosm study. Journal of Hazardous Materials, 415(8), 125615; https://doi.org/10.1016/j.jhazmat.2021.125615

Diaz F.J., O'Geen A.T., Dahlgren R,A., Efficacy of constructed wetlands for removal of bacterial contamination from agricultural return flows. Agricultural Water Management 2010, 97(11), s. 1813-1821; https://doi.org/10.1016/j.agwat.2010.06.015

Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy. Available online: https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX%3A32000 L0060 (accessed on 8 January 2022).

Jakubowicz P., Fitobór K., Gajewska M., Drewnowska M., (2022) Detection and Removal of Priority Substances and Emerging Pollutants from Stormwater: Case Study of the Kołobrzeska Collector, Gdańsk, Poland, Sustainability 2022, 14(3), 1105; https://doi.org/10.3390/su14031105

Langergraber, G., Castellar, J.A.C., Andersen, T.R., Andreucci, M., Baganz, G.F.M., Buttiglieri, G., Canet-Martí, A., Carvalho, P.N., Finger, D.C., Bulc, T.G., Junge, R., Megyesi, B., Miloševi, D., Oral, H.V., Pearlmutter, D., Pineda-Martos, R., Pucher, B., D. van Hullebusch, E. and Atanasova, N. 2021. Towards a Cross-Sectoral View of Nature-Based Solutions for Enabling Circular Cities, Water 13; https://doi.org/10.3390/w13172352

Long Y, Zhou Z, Wen X, Wang J, Xiao R, Wang W, Li X, Lai X, Zhang Y, Deng C, Cao J, Yin L., (2023) Microplastics removal and characteristics of a typical multi-combination and multi-stage constructed wetlands wastewater treatment plant in Changsha, China. Chemosphere 2023, 312, 137199; https://doi.org/10.1016/j.chemosphere.2022.137199Moore D.F., Guzman J.A., McGee C. Species distribution and antimicrobial resistance of enterococci isolated from surface and ocean water. Journal of Applied Microbiology 2008, 105(4), s. 1017-1025; https://doi.org/10.1111/j.1365-2672.2008.03828.x

Oral, H.V.; Carvalho, P.; Gajewska, M.; Ursino, N.; Masi, F.; Hullebusch, E.D. van; Kazak, J.K.; Exposito, A.; Cipolletta, G.; Andersen, T.R.; et al. 2020. A Review of Nature-Based Solutions for Urban Water Management in European Circular Cities: A Critical Assessment Based on Case Studies and Literature. Blue-Green Syst. 2; https://doi.org/10.2166/bgs.2020.932

Zhou X., Pan Z., Wang W., Ren J., Yu X., Lin L., Lin H., Chen H., Jin H.,(2022) Microplastic abundance, characteristics and removal in large-scale multi-stage constructed wetlands for effluent polishing in northern China. Chemical Engineering Journal , 430(1), 132752; https://doi.org/10.1016/j.cej.2021.132752

Removal performance of different types of bioelectrochemical constructed wetlands for dairy wastewater treatment.

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Keywords: dairy wastewater, granular activated carbon, bioelectrochemical constructed wetlands, voltage

ABSTRACT

The dairy industry belongs to the agri-food sector, producing a large volume of products such as milk, milk powder, butter and cheese (Ahmad et al., 2019). It is one of the driving sectors in the agricultural economy due to its substantial demand. However, dairy production requires a large volume of water for the processes, approximately eight times the volume of milk (Ekka et al., 2022). As a result, it also contributes to one of the largest sources of industrial wastewater. Dairy wastewater contains high concentrations of organic contaminants like carbohydrates, proteins, lactose, grease and oil (Ekka et al., 2022). Additionally, It contains high amounts of organic matter, with chemical oxygen demand (COD) ranging from 80 to 95,000 mg/L, as well as high concentrations of total suspended solids (TSS), total nitrogen (TN), total phosphorus (TP), and pH variations ranging from 4 to 11 (Ahmad et al., 2019).

One possible management practice that has been used in recent years for the treatment of agricultural and livestock wastewater is constructed wetlands (CWs) (Mohamed et al., 2022). CWs are an environmentally friendly and cost-effective technology for managing dairy by-products (Tunçsiper et al., 2015). They are designed and constructed to use the natural processes occurring in plants, substrates and microbial communities to treat wastewater (Gorra et al., 2014). The large surface area and the use of substrates facilitate the development of different microbial processes which act as catalysts in removing both organic and inorganic components from the wastewater (Gorra et al., 2014).

On the other hand, the large surface area requirements to achieve the same treatment efficiency as conventional systems is a problem in areas where land is not available or where land costs are high. To address this challenge, the integration of constructed wetlands (CWs) with bioelectrochemical systems has been proposed recently. Bioelectrochemical technology is an environmental friendly technology with minimal or zero energy input (Wang et al.,2021). When CWs are coupled with bioelectrochemical systems, the CWs provide the necessary redox gradient for the deployment of electrodes. This study aims to develop innovative bioelectrochemical constructed wetlands that can achieve high treatment efficiencies using a much smaller surface area compared to typical CWs used for dairy wastewater treatment. The development of bio-electrochemical constructed wetlands was carried out by combining microbial fuel cells and microbial electrolysis cells with vertical up-flow constructed wetlands.

The experimental bioelectrochemical constructed wetlands were constructed using modified cylindrical plastic tubes (diameter: 20 cm, height: 50.5 cm). Figure 1 shows the schematic diagram of the four examined reactors named CCW (conventional constructed wetland), CW-MFC (constructed wetland-microbial fuel cell), CW-MEC (constructed wetland-microbial electrolysis cell) and OCW-BES (open-circuit constructed wetland-bioelectrochemical system). The CW-MFC, CW-MEC, and OCW-BES consisted of, an anode and cathode layer (4cm) filled with activated carbon.. The main layer of the CWs comprised a mixture (1:1) of perlite (1-5 mm) and LECA (8-16 mm). Iris sp. plants were used as vegetation in each system. Dairy wastewater was obtained from a local cheese factory and stored at 4 ^{o}C prior to use. Influent and effluent samples were collected weekly for a period of about 6 months. During the first 116 days (named phase A) of the experiment the systems operated receiving dairy wastewater at a hydraulic loading rate (HLR) of 64 mm/d, in the second phase lasted 58 days (named phase B) the HLR was 183mm/d.

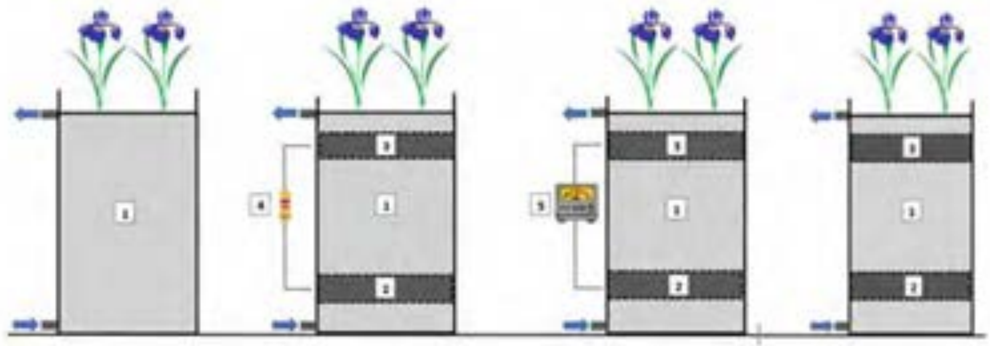

Fig.1: Schematic presentation of the experimental set-up. From left to right: a) Typical vertical up-flow constructed wetland (CCW); b) Constructed Wetland-Microbial Fuel Cell (CW-MFC); c) Constructed Wetland-Microbial Electrolysis Cell (CW-MEC) and d) open-circuit constructed wetland-bioelectrochemical system (CW-BES) 1: mixture of perlite and lightweight expanded clay (LECA), 2: anode electrode (activated carbon), 3: cathode electrode (activated carbon), 4: resistor 220 Ωhm, 5: power supply.

The influent and effluent samples were analyzed for turbidity, EC, pH, TSS, VSS, COD, BOD, TP. The pH was measured using a pH-meter (C932, Consort), and the Electrical conductivity (EC) using a portable conductimeter (LF95, WTW). Turbidity was monitored using a portable turbidimeter (2100Q, Hach). Moreover, TSS,VSS, COD, and TP, analyses were conducted according to APHA (APHA et al.,2005). Biochemical oxygen demand (BOD) was determined using the closed respirometric method (OxiTop®, WTW).

Table 1: Chemical characteristics of dairy wastewater used in the experiment.

Parameter	Dairy wastewater phase A mean ± SD (number of samples)	Dairy wastewater phase B mean ± SD (number of samples)
pH	4.5 ± 0.7 (19)	3.7 ± 0.2 (8)
EC (μS/cm)	2324 ± 1413 (19)	3804 ± 341 (8)
Turbidity (FNU)	922± 488 (19)	796 ± 545 (8)
COD (mg/L)	4622 ± 1628 (19)	2396 ± 611 (8)
BOD_5 (mg/L)	1186 ± 207 (19)	2226 ± 450 (8)
VSS (mg/L)	405 ± 282(19)	250 ± 161 (8)
TSS (mg/L)	407 ± 289 (19)	254 ± 166 (8)
Total-P (mg/L)	2.5 ± 1.8 (19)	3.2 ± 0.3 (8)

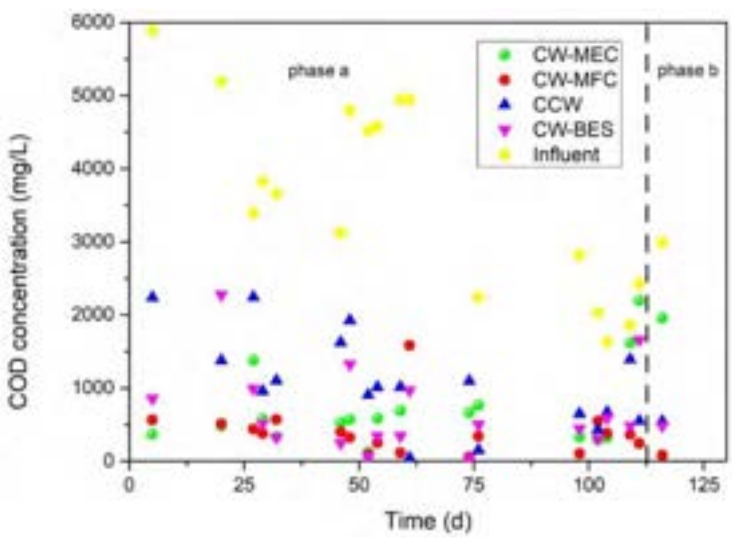

Fig.2: COD concentration in the influent and the effluents of the bioelectrochemical constructed wetlands during the experimental period.

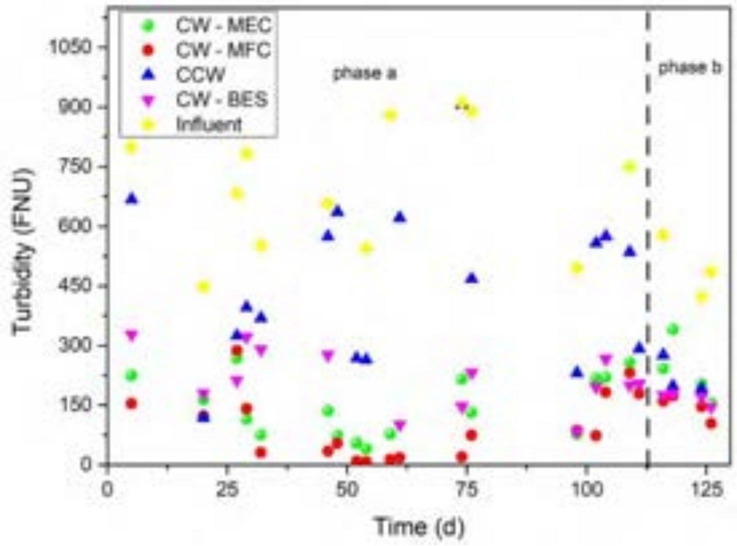

Fig.3: Turbidity concentration in the influent and the effluents of the bioelectrochemical constructed wetlands during the experimental period.

In the first phase of the experiment, the turbidity in the influent was 889 ± 496 FNU while the average turbidity in the effluents of CW-MEC, CW-MFC, CCW, and CW-BES were 133±71 FNU, 110±72 FNU, 457±206 FNU,215±80 FNU, respectively. In the second phase of the experiment, the influent had a turbidity value of 796±545FNU while the effluents were 229 ± 60 FNU, 168 ± 39 FNU, 345 ± 169 FNU, and 191 ± 38 FNU, respectively. Turbidity showed a decreasing trend in both the first and the second phase of the experiment however, in the first phase the turbidity removal efficiency was better (CW-MEC:86%, CW-MFC:88%, CCW:50%, CW-BES:77%), compared to the second phase of the experiment (CW-MEC:59%, CW-MFC:70%, CCW:38%, CW-BES:66%) showed a decreased performance.

The dairy wastewater used in this experiment had a COD concentration of 4622 ± 1628 mg/L and a BOD5 concentration of 1186 ± 207 mg/L during the first phase of the experiment. In the second phase of the experiment the COD concentration in the influent was 2396 ± 611 mg/L and the BOD_5 concentration was 2226 ± 450 mg/L. As shown in Fig. 2, the COD concentration in the effluents of both systems decreases considerably in both phases. The COD removal efficiency was 86%, 90%, 72%, and 84% for CW-MEC, CW-MFC, CCW, and CW-BES respectively. In the second phase, the Increase of the HLR from 64 mm/d to 183mm/d appears to have had a negative effect on organic load removal efficiency however the pollutants removal efficiency remained high at 80%, 89%, 80%, and 79% for CW-MEC, CW-MFC, CCW, and CW-BES respectively. The COD removal in the CW-MFC system appears to be better in both phases of the experiment compared to the CCW control system since as reported by Fang et al. (2017), a CW-MFC system is able to remove COD loads up to 90%.

The objective of this study was to develop innovative bioelectrochemical-constructed wetlands that can achieve high treatment efficiencies using a much smaller surface area than typical artificial wetlands for dairy wastewater treatment. The use of bio-electrochemical constructed wetlands (combining microbial fuel cells and microbial electrolysis cells) seems to have higher removal rates for all examined parameters (Turbidity, TSS, VSS, BOD5, COD, TP) compared to the other two systems.

References:

APHA,(2005). Standard Methods for the Examination of Water and Wastewater . American Public Health Association (APHA), American Water Works Association (AWWA), and Water Environment Federation (WEF).

Ahmad, T., Aadil, R. M., Ahmed, H., Rahman, U. ur, Soares, B. C. V., Souza, S. L. Q., Pimentel, T. C., Scudino, H., Guimarães, J. T., Esmerino, E. A., Freitas, M. Q., Almada, R. B., Vendramel, S. M. R., Silva, M. C., & Cruz, A. G. (2019). Treatment and utilization of dairy industrial waste: A review. In Trends in Food Science and Technology (Vol. 88, pp. 361–372).

Ekka, B., Mieriņa, I., Juhna, T., Turks, M., & Kokina, K. (2022). Quantification of different fatty acids in raw dairy wastewater. Cleaner Engineering and Technology, 7.

Fang, Z., Cheng, S., Cao, X., Wang, H., Li, X., 2017. Effects of electrode gap and wastewater condition on the performance of microbial fuel cell coupled constructed wetland. Environ. Technol. 38, 1051–1060. https://doi.org/10.1080/09593330.2016.1217280 (United Kingdom)

Gorra, R., Freppaz, M., Zanini, E., & Scalenghe, R. (2014). Mountain dairy wastewater treatment with the use of a “irregularly shaped” constructed wetland (Aosta Valley, Italy). Ecological Engineering, 73, 176–183.

Mohamed, A. Y. A., Siggins, A., Healy, M. G., Ó hUallacháin, D., Fenton, O., & Tuohy, P. (2022). A novel hybrid coagulation constructed wetland system for the treatment of dairy wastewater. Science of the Total Environment, 847.

Tunçsiper, B., Drizo, A., & Twohig, E. (2015). Constructed wetlands as a potential management practice for cold climate dairy effluent treatment - VT, USA. Catena, 135, 184–192

Performance of pilot-scale constructed wetlands with different designs and substrates treating olive mill wastewater

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Keywords: constructed wetlands, olive mill wastewater, circular economy, substrate media

ABSTRACT

The adoption of unsustainable cropping practices (excessive tillage, monoculture), as well as the increasing impact of intense heat waves and prolonged droughts due to climate change have amplified concerns about soil erosion, soil organic matter depletion, groundwater contamination and water resource degradation and loss of biodiversity. The ReMe-diation project brings a holistic approach to problems with soil, water, energy and biodiversity in the Mediterranean area. The project investigates several aspects including 1) establishing an intercropping system in an olive grove by introducing local leguminous crops; 2) implementing a nature-based solution, i.e., constructed wetlands, for the treatment of wastewater from the cork and olive oil industry in Portugal and Greece; 3) producing biochar from agricultural residues; 4) producing biogas from organic residues/biomass; and 5) recovering high value-added products.

This study focused on the use of different constructed wetland designs for the treatment of olive mill wastewater in pilot-scale experiments, and presents the results of the first 5 months of operation.

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Floating constructed wetlands based on recycled polymers to restore aquatic ecosystems

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Keywords: Floating constructed wetlands, recycled polymers, aquatic ecosystems

ABSTRACT

Floating wetlands (FWs) are systems that are widely used to improve water quality. FWs are an innovative tool for nutrient control in low water ow locations. They involve emergent wetland plants which grow in floating baskets moored above the surface of the water. Plant roots germinate through these forming a cover within the water. Just as there is an assimilation of nutrients directly from the water column, instead of the soil, the roots provide an extensive surface area for the absorption and use of the biofilm for transformation of contaminants. Because FWs can tolerate depths and fluctuations in water levels, they come to be used in situations where the use of conventional wetlands would be impossible. In naturally FWs, self-flotation occurs either by trapping gases within the mat or by air spaces between the roots. FWs are supported by a constructed floating medium, typically composed of materials such as plastic, inorganic fibers, or fiberglass. A large number of alternative technologies and materials have been tested to ensure the buoyancy of the floating frame, and to date there are a large number of commercially patented systems. However, in very little research and patents, they have been used recycled materials to generate the bases of the floating wetlands. The objective of this research was evaluate the buoyancy and pollutant removal efficiencies when using floating wetlands with recycled polymers to treat water from an urban canal. To carry out this research, two floating wetland systems were built with recycled polymers using two species of emergent macrophytes, *Schoenoplectus californicus* and *Phragmites australis*. Each system presented 12 baskets to inoculate the plants in the floating wetland. The systems were implemented in an urban channel and monitored for 41 days. Based on aerial leaf biomass coverage (12 adult seedlings), the floating wetlands were able to assimilate 0.0264-0.132 gN/m^2 and 0.040-0.21 gN/m^2 for *Phragmites australis* and *Schoenoplectus californicus*, respectively. In turn, the system was able to maintain buoyancy of up to 10 pairs of plants with a maximum weight of 1.5 kg each. FWs are a growing treatment alternative, which is currently being studied and evaluated as a treatment system with great potential. Not only because of its treatment capacity, but also because could be generate a greater added value is generated when the inputs of the treatment system are designed and made with recycled reused materials, as is the case in this research.

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References:

Lynch, J., Fox, L. J., Owen Jr, J. S., Sample, D. J. 2015. Evaluation of commercial floating treatment wetland technologies for nutrient remediation of stormwater. Ecological Engineering, 75, 61-69. https://doi.org/10.1016/j.ecoleng.2014.11.001

Pavlineri, N., Skoulikidis, N. T., Tsihrintzis, V. A. 2017. Constructed floating wetlands: a review of research, design, operation and management aspects, and data meta-analysis. Chemical Engineering Journal, 308, 1120-1132. https://doi.org/10.1016/j.cej.2016.09.140

Selecting innovative substrates materials: characterization and potential application for enhancing CWs sustainability

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Keywords: CWs, innovative substrate, leaching, metals, footprint, hydraulics properties

ABSTRACT

This study provides preliminary evaluations of sustainable and efficient alternatives of materials for possible applications as filtering substrates for CWs footprint reduction. A lab-scale vertical CW system was set-up for testing: two classes of volcanic ashes of Mt. Etna volcano (Italy), artisan spherical beads made of volcanic ashes-biochar-based alkali-activated material and slag from construction activities, both individually and in complete profile settings. Leaching and hydraulic tests for assessing their chemical stability, metals release and hydraulic properties were performed. Also, electrical resistivity tomography (ERT) tests and monitoring on treatment of domestic WW are ongoing. The preliminary results suggest for some material advisable preliminary management like washing procedure before use. Treatment efficiencies will be also evaluated at the light of the Italian and European standards for water reuse in agriculture.

Introduction

Filtering substrate is a key component in subsurface constructed wetlands (CWs) (Wang et al., 2018). As decentralized treatment systems for water reuse in small and medium civil and agro-industrial settlements, CWs efficiency requires to be optimized for spatial and environmental footprint reduction. Simultaneous enhanced treatment performance and sustainability could be achieved by using efficient substrate materials, like wastes recovered from natural and/or industrial processes. Wang et al. (2018) reported the high potential improvement in the research on the development of new substrates in CWs, highlighting the superior efficiency of combined substrates compared to single ones. In the view of Ecological transaction point of view, alkali activated materials (AAMs) represent a green alternative to traditional building materials based on Ordinary Portland Cement (OPC) due to their low environmental impact in terms of emission and energy consumption (Provis and Bernal, 2014). They are made by the mixing of an aluminosilicate powder (i.e., precursor) and an alkaline solution (i.e., activator) (Provis and van Deventer, 2014). In this scenario, Barone et al., (2021a) have already described the use of pyroclastic deposits of Mt. Etna volcano (Italy) for the production of AAMs as a great valorisation opportunity of this natural waste material, whose management is very expensive for the local communities. Recently, the use of biochar as innovative substrate material in CWs is becoming ever more attractive due to their energy-saving and environmentally friendly advantages, together with high wastewater (WW) treatment performance (Xing et al., 2021), despite further studies are required (Deng et al., 2021). This work wants to evaluate the chemical-physical and hydraulic properties of volcanic ash, spherical beads made of volcanic ash-biochar-based alkali-activated material and slag from construction activities as suitable alternatives for application in vertical CWs for WW treatment. In detail, they were characterized in terms of potentially toxic elements (PTEs) leaching and hydraulic features.

The ongoing experimental activities are focusing on 4 lab-scale vertical CWs, filled each one with each tested material, for evaluating: i.) the treatment efficiency of domestic WW in terms of *E. coli* reduction, COD, NH^{+}_{4}, TN and TP removal for water reuse; ii.) the flow distribution and K_s, respectively, through electrical resistivity tomography (ERT) and constant head permeameter.

Material and Methods

Substrates: origin and manufacture

In this work, volcanic ash coming from Mt. Etna volcano (Italy) was used as precursor for the alkaline activation process. After sampling, the volcanic ash has undergone a quick washing and then a dry milling to obtain a grain size < 75 µm. The activating solution is here obtained by the combination of sodium hydroxide (8M), sodium silicate (provided by Ingessil s.r.l.) with a molar ratio SiO_2/Na_2O = 2 and tap water. In detail, a binder based on volcanic ash was produced by adding 10 wt.% of metakaolin (M) as solid additive to the total amount of volcanic powder used, following the satisfying results obtained by other authors (Barone et al., 2021a). To the binder, 5 wt. % of biochar (from wood chips, Ø 500-5000 µm, provided by RESET s.r.l) was added to the mixture for producing *artisan* spherical beads made of volcanic ash-biochar-based AAM. Pyroclastic particles were sampled near the Santa Venerina town (in the south-east slope of Mt. Etna volcano, Italy), after the 2013 eruption and they have been sieved in two dimensional classes, namely V1 and V2, whose grain sizes are reported in Figure 1.

CWs lab-plant

The lab-scale plant scheme is reported in Figure 1. It consists of 8 columns, operating in parallel. All the columns are filled with a common vertical profile, differing just for one of the four substrates tested, which is proposed in duplicates.

The vertical profile of filling materials is constituted from the top to the bottom by commercial volcanic sand (0-3 mm), the tested material (volcanic ash "V1", volcanic ash "V2", slag "SL" and AAM volcanic ash-biochar "BA"), volcanic sand (0-6 mm), and coarse volcanic gravel (12-15 mm).

Domestic WW feeds intermittently the columns after passing through an Imhoff and a regulation tank. Hydraulic loading rates (HLR) of 30, 90, 160 e 240 mm d^{-1} are applied in total to the CW system but divided into 6 cycles/day. COD, TN, NH^{+}_{4}TP are determined by spectrophotometry and ionic chromatography. The removal efficiencies are calculated as mean values of two columns with the same substrate configuration.

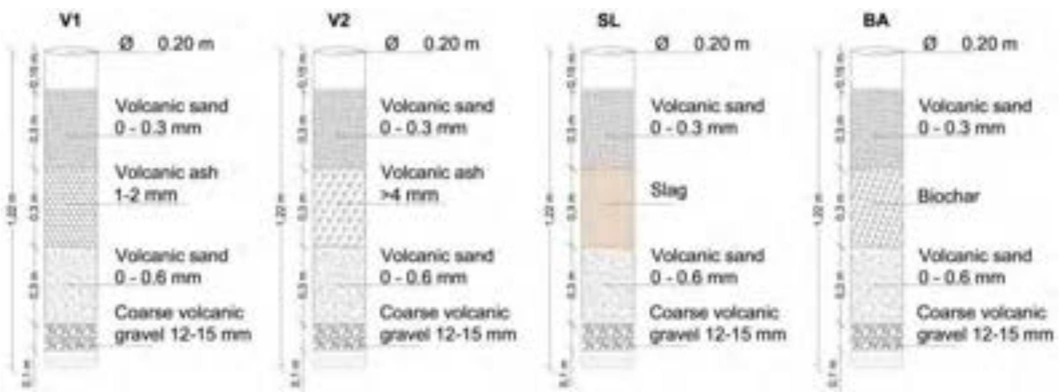

Figure 1. Experimental layout of 4 lab-scale vertical CWs (each test is duplicated; the entire system presents 8 parallel units).

Substrates hydraulic characterization

Hydraulic tests were conducted in the columns only with the investigated substrates materials. The constant-head (CH) permeameter is a broadly used and well documented laboratory instrument to determine the saturated hydraulic conductivity (K_s) of a wide range of samples including CW filter media (Pedescoll et al., 2012). The K_s has been determined by combining Darcy's law and averaging (*n=4*) measured data of the water flow rate through each substrate. For porosity (ϕ) determination, the simple saturation method (Fonteno and Harden, 1995) has been used, while permeable porosity tests for water absorption (W_a%) were assessed similarly to the procedure adopted by Barone et al., 2021b.

Chemical stability and leaching tests

Similarly with other studies, the chemical stability (Barone et al., 2021a) and metals leaching (Barone et al., 2021b) were tested in the different substrates exposed to WW and to de-ionized water for analytical use (WA). The leachant has a widespread use because it allows a rapid screening of the PTEs easily leached from the ash, while the release of elements in natural water can be different from that observed in deionised water. For this study, a substrate/aqueous matrix ratio equal to 50:500 g/mL was used. Each sample has been agitated using a magnetic stirrer at a room temperature (on average 23°C ± 2.5) for 5 days, by changing every 24 hours only the aqueous matrix but exposing the same substrate, in order to avoid saturation phenomena which could limit the leaching trends. During the leaching experiments, the variations of T, pH and electrical conductivity (EC) were respectively measured and recorded by: Campbell instruments (CSIM11-L pH probes, 107 Thermistor probe, datalogger CR1000X) and by the Deltaohm conductivity-thermometer datalogger (HD2106.2). Metals concentrations (Al, V, Cr, Co, Mn, Ni, As, Se, Cd, Sb, Pb, B, Fe, Zn, Sn, Ba, Tl) have been quantified by inductively coupled plasma-mass spectrometry (ICP-MS) Elan-DRC-e (Perkin-Elmer, USA) on raw WW and leachates samples filtered (Chromafil Xtra RC-45/25).

RESULTS

The expected suitability of WA as rapid screening for contaminant leaching was observed in the case of both volcanic ashes and less for BA and SL. In detail, the pyroclastic deposits exhibited relatively higher values of EC with respect to the exposition to WW, while the other evidenced more complex pH and EC trends in both WA and WW. In particular, V1 and V2 showed high chemical stability, with no differences in pH trends even considering the initial WW characteristics (pH ≈ 8.15; EC ≈1800 μScm^{-1}). BA displayed high peaks in pH (>10) and EC (>6000 μScm^{-1}), but with lower extension and faster recovery in the case ofWW exposition, suggesting some buffering effect offered by their background concentrations. SL did not differ in pH and EC trends between WA and WW even if in the last case the EC reached values higher than4000 μScm^{-1}. However, both BA and SL evidenced values higher than the Italian standards for water reuse(D.M. 185/2003), achieving the compliance only after two or three days of testing.

Preliminary observations on metals release trends differed in relation to the element and the leaching matrix, but these have still to be confirmed. Most evidently, Al, V, Cr and Fe were released both in WW and in WA. In particular, higher concentrations were observed in V1-WA e BA-WW for Al, BA-WW for V, V2-WW, SL-WW and BA-WW for Cr, and in any case in SL and BA for Fe. Co, Cd, Pb and Zn were mainly released in WW, with higher concentrations in V2-BA, SL, V1-BA and V1-V2, respectively.

Preliminary results on the hydraulic characterization highlighted a direct correlation between porosity and K_s trends. However, the SL displayed higher Ks variability due to a wide granulometric range, while this trend was inverse in the case of BA. Water absorption ranged between 9 and 26%, with the highest values for volcanic ashes and the lowest for the slag material.

DISCUSSION AND CONCLUSIONS

Due to their origin as natural or industrial wastes, alternative substrates materials should be previously assessed in terms of chemical stability and PTEs leaching capacity before their use for WW treatment and reuse. Generally, the tested materials were compliant to the Italian normative for water reuse (M.D. 185/2003) with respect to metals release in WW. During the initial phases of trials, the use of slag from construction activities (SL) increased in electrical conductivity (EC), whereas the use of biochar (BA) increased both the pH and the EC. However, only a few metals were released, and their concentrations did not exceed the maximum allowed limits (i.e., Al 1, V 0.1, As 0.02, Cd 0.005 mg L-1). Nevertheless, to mitigate any potential adverse effects, a washing procedure prior to use is recommended. Other materials, such as volcanic sand and not-aggregated biochar derived from wood chips (provided by RESET s.r.l.), have shown high treatment performances for COD removal (>90%) and E. coli reduction (up to 9 log10 CFU

100mL-1) under similar experimental conditions, even when higher hydraulic loading rates (HLR) were applied (Milani et al., 2019). This latter work also demonstrated the usefulness of electrical resistivity tomography (ERT) technique for characterizing the resistive properties of different substrates. However, after several months of operation, the biochar's treatment performance was inhibited due to porosity reduction and material compaction. The hydraulic characterization of the materials investigated in this study revealed lower Ks values for BA, even with comparable porosity to the other materials, and a wide range of water absorption rates. Ongoing ERT and Ks measurements on the entire testing columns and monitoring of wastewater quality will provide a comprehensive profile of the hydraulic behaviour and treatment performance of each material investigated. Treatment efficiency will also be evaluated for quality parameters according to the EU regulation for agricultural reuse of reclaimed water in class A, which permits the use of reclaimed water for all food crops, including root crops consumed raw.

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References:

Barone, G. et al., 2021a. Potentiality of the Use of Pyroclastic Volcanic Residues in the Production of Alkali ActivatedMaterial. Waste and Biomass Valorization, 12(2), 1075–1094.

Barone, G., et al., 2021b. Surface reactivity of Etna volcanic ash and evaluation of health risks. Science of The TotalEnvironment, 761, 143248.

Deng, S. et al., 2021. Application of biochar as an innovative substrate in constructed wetlands/biofilters forwastewater treatment: Performance and ecological benefits. Journal of Cleaner Production, 293, 126156.

Fonteno, W. C. and Harden, C. T., 1995. Procedure for determining physical properties of horticultural substrates using the NCSU porometer, 27.

Milani, M. et al., 2019. “Performance of different substrates in vertical subsurface flow constructed wetlands” in Book of Abstracts. Wetpol - 8th International Symposium on Wetland Pollutant Dynamics and Control. Aarhus University - Denmark, 251.

Pedescoll, A. et al., 2012. A Comparison of In Situ Constant and Falling Head Permeameter Tests to Assess the Distribution of Clogging Within Horizontal Subsurface Flow Constructed Wetlands. Water, Air, & Soil Pollution, 223(5),2263–2275.

Provis, J. L. and Bernal, S. A., 2014. Geopolymers and Related Alkali-Activated Materials. Annual Review of MaterialsResearch, 44(1), 299–327.

Provis, J. L. and van Deventer, J. S. J. (eds.), 2014. Alkali Activated Materials, Dordrecht, Springer Netherlands. http://link.springer.com/10.1007/978-94-007-7672-2 (Accessed May 24, 2022).

Wang, H. X. et al., 2018. A Review of Research on Substrate Materials for Constructed Wetlands. Materials Science Forum, 913, 917–929.

Xing, C., et al., 2021. Study on the Decontamination Effect of Biochar-Constructed Wetland under Different HydraulicConditions. Water, 13(7), 893.

Smart monitoring of waste-filled constructed wetlands for the removal of nutrients from wastewater with low carbon content

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ABSTRACT

Constructed wetlands (CW) are an eco-friendly nature-based approach to treating wastewater. These systems use natural processes to break down and remove pollutants from wastewater, reducing the need for expensive and energy-intensive treatment methods (Cross et al., 2021). The idea behind constructed wetlands is to mimic the natural processes of wetlands, which are known to effectively filter pollutants from water. In these man-made systems, wastewater is directed through impermeable, planted basins designed to remove contaminants and nutrients (Wu et al., 2023).

In recent years, waste-filled constructed wetlands have gained attention as a promising approach for reducing the implementation cost of constructed wetlands. These systems utilize waste materials, such as coal slag from thermal power plants, gravel, and construction waste, among others, as filling material to effectively treat wastewater while also providing a sustainable solution for waste disposal (Mateus and Pinho, 2020).

To further explore the potential of waste-filled constructed wetlands, two pilot-scale constructed wetlands, filled with waste materials were monitored. These systems were used for the advanced treatment of a wastewater with high content of the nutrients Phosphorus (P) and Nitrogen (N) and low organic carbon content.

This study also aimed to apply smart monitoring systems to CW, based on IoT technology and electrochemical sensors. Using water quality sensors, such as pH, electrical conductivity (EC), and ions sensitive sensors (nitrates, ammonium, and phosphates), real-time data can be gathered providing a better understanding of pollutant removing mechanisms by CW. Furthermore, recent radiation-absorption-based sensors provide the evaluation of extended parameters such as COD.

Materials and methods

This study reports the wastewater treatment efficiency of 2 pilot-scale waste-filled CW, from February to June 2023. The CWs are placed outdoors, under field conditions, at the Tomar Polytechnic Institute *campus*. The CWs were operated in a continuous horizontal subsurface flow mode and were planted with the reed *Phragmites australis*. The CWs were continuously fed with secondary-treated domestic wastewater, with P and N contents above that allowed by the legislation for discharge into the water environment, and low organic matter content. The CW-E was operated in a continuous mode since 2009 (Mateus et al., 2012) and CW-P was operated also in a continuous mode since 2019 (Pinho and Mateus, 2022).

The CW-E consists of a 1.1 m long × 0.9 m wide × 0.56 m deep rectangular PVC tank, filled with limestone fragments, a mineral waste that originated during the processing of stone for construction tiles (Mateus et al., 2012). The CW-P (1.2 m long × 1 m wide × 0.5 m deep rectangular modular wood tank) was filled with limestone fragments, coal slags (mineralized alumina-silicate waste sourced from coal power plants) and cork granulates (lignocellulosic waste sourced from cork processing industries) in a four-layer arrangement (Pinho and Mateus, 2022).

Analytical Procedure

The wastewater quality indicators, in particular chemical oxygen demand (COD), nitrates (NO_3^--N), nitrites (NO_2^--N), ammonia (NH_3-N), total nitrogen (TN), phosphates (PO_4^{3-}P), and total phosphorus (TP), were determined by adaptation of standard methods for the multiparameter photometer with COD HI83399, from Hanna instruments (DE). The conductivity and pH were measured using the multiparameter GroLine Monitor - HI981421 from Hanna instruments (DE).

The preliminary setting of an IoT-based framework is ongoing to provide real-time data acquisition from CW-P. In its current version, this framework includes a set of ion-sensitive sensors (CG200, CleanGrow, UK), pH and EC probes (AtlasScientific, USA), and a COD probe (Zata, HK).

Results and Discussion

The performance of the CW-E and CW-P, for the monitored period, are shown in Table 1 and Fig. 1.

Table 1 shows the inlet and outlet water means of the analysed parameters, namely flow rate, pH, conductivity TN, TP, CQO, NH_3-N, NO_2^- and PO_4^{3-}. The results obtained for NO_3^{2-}-N, in the inlet and outlet water of the two systems, are close to zero.

Fig. 1a) shows the variation, in inlet and outlet water, of COD and its removal efficiency; Fig. 1b) shows the variation of NH_3-N and TN concentrations, and TN removal efficiency; and Fig. 1c) shows the variation of PO_4^{3-} and TP concentrations, and TP removal efficiency.

Table 1 Mean values ± 95% confidence interval for water quality indicators

		Flowrate (L/day)	pH	EC (mS/cm²)	TN (mg/L)	TP (mg/L)	COD (mgO_2/L)	NH_3-N (mg/L)	NO_2^- (mg/L)	PO_4^{3-} (mg/L)
CW-E	Inlet	19.9±5.2	7.4±0.2	0.36±0.07	26.6±6.2	5.8±1.8	24.7±4.61	27.5±6.9	0.05±0.02	5.5±1.6
	Outlet	14.2±6.8	7.1±0.4	0.48±0.06	3.1±1.1	3.1±1.0	7.3±1.0	0.5±0.7	0.02±0.03	2.7±0.8
CW-P	Inlet	19.7±4.7	7.2±0.5	0.27±0,04	17.7±2.8	3.4±0.8	62.9±26.3	17.1±2.8	0.05±0.07	3.0±0.7
	Outlet	15.6±7.0	7.3±0.3	0.39±0.08	2.0±1.2	1.0±0.3	9.1±0.31	0.8±1.3	0.01±0.01	1.0±0.5

The influent water has a low content in COD, particularly in CW-E, the COD:N ratio is lower than the recommended for the efficiency of the denitrification process (Liwarska-Bizukojć et al., 2018). Nevertheless, the TN removal efficiency is very satisfactory, and the outlet concentration of nitrates is close to zero, fulfilling the legal requirements for TN content in discharge water. These results indicate that waste-filled CW can be a good approach for nutrient removal of water with low COD contents, dispensing the need for an external source of carbon. This can be explained by the fact that the plants or solid waste such as coal slag and cork granulate can act as a continuous source of organic matter avoiding the need for an external C source.

In the monitored period, the removal rate of nitrogen and phosphorous compounds show average values of 89% for nitrogen and 69% for phosphorous compounds in CW-E, 93% for nitrogen, and 77% for phosphorous compounds in CW-P.

The content of TP and phosphates are very similar in the influent and effluent water of both CWs. The same was observed for the TN and NH_3-N, indicating that phosphates are the main source of phosphorus and ammonia is the main source of nitrogen in the water and were positively correlated (Pearson correlation of 0.962, df=38, $p<0.01$ for TN/NH_3-N, and 0.954, df=38, $p<0.01$ for TP/PO_4^{3-}-P). These results consist of a favourable condition to allow the use of ammonia and phosphate sensors for monitoring the efficiency of the CW systems.

The COD probe was tested in April and May of 2023, with a gathering frequency of 10 minutes. COD data obtained ranged from 6 to 11 mgO_2/L, with an average value of 8.8 and a standard deviation of 1.2. In this period, COD evaluated by chemical analysis ranged from 4 to 10 mgO_2/L, with an average value of 7 and a standard deviation of 3. Although further work is being done to calibrate and validate the use of the COD probe, the preliminary results obtained are promising for future real-time evaluation of the COD removal efficiency of CW and other nature-based solutions for wastewater treatment.

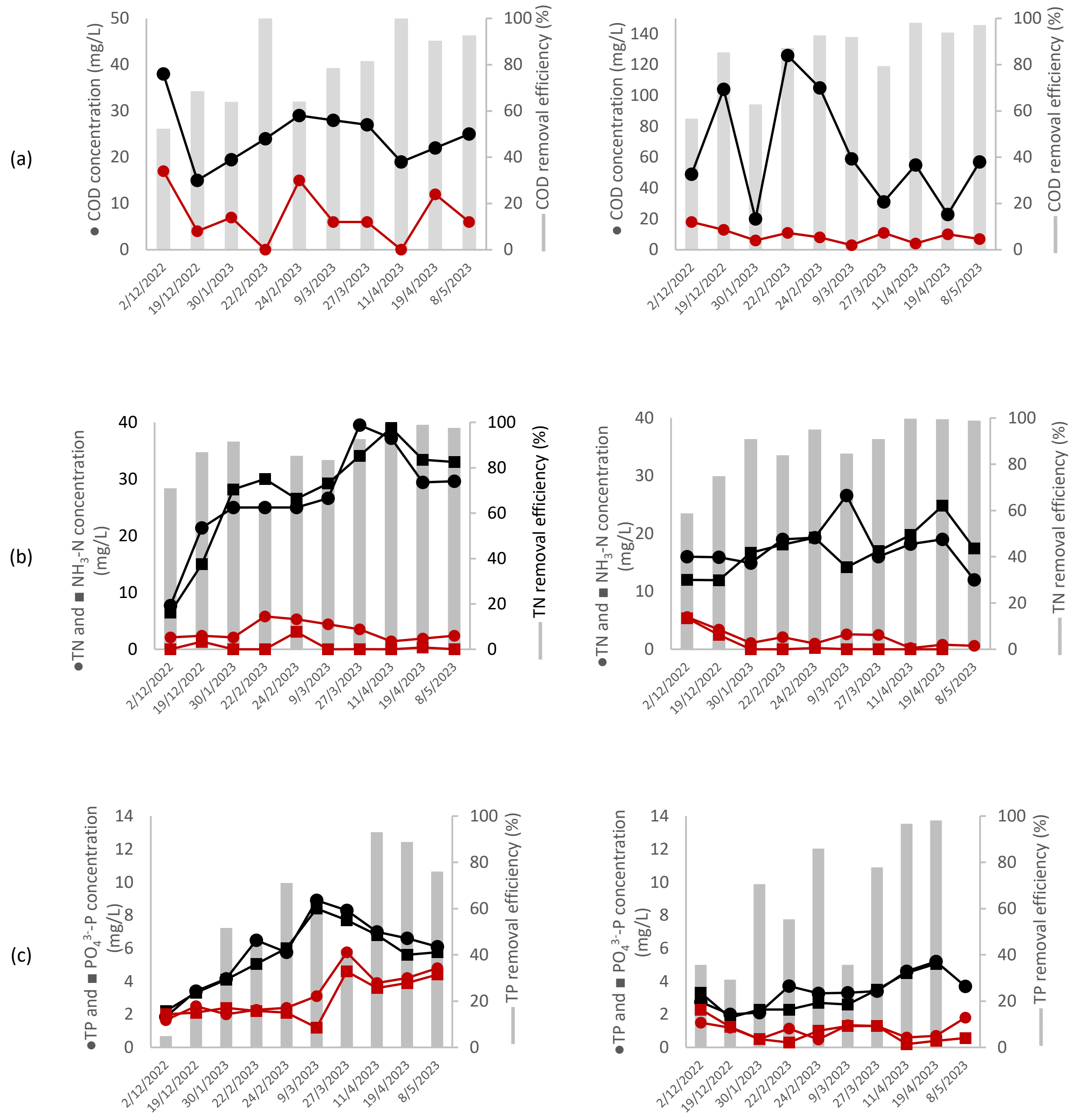

Fig. 1 Concentrations and removal efficiency for COD (a); Concentration of TN and NH_3-N, and removal efficiency for TN (b); Concentration of TP and PO_4^{3-}-P, and removal efficiency for TP (c). ▬ inlet concentration ▬ outlet concentration. The bars show the removal efficiencies. Graphs on the left are for CW-E, and graphs on the right are for CW-P.

Conclusions

The obtained results showed that waste-filled constructed wetlands were able to effectively reduce nutrient levels in the treated wastewater without the need for an external carbon source.

The total phosphorus content was found to be positively correlated with phosphate levels and the total nitrogen was found to be also positively correlated with ammonia levels, indicating that phosphates and ammonia are the main sources of phosphorus and nitrogen respectively in the wastewater. In that conditions, ammonia and phosphate electrochemical sensors can be used for real-time monitoring of CW and other nature-based systems.

COD of the treated wastewater also correlates well with the data gathered from a COD probe. Although further work is needed to validate this result, a way is open to provide low-cost and real-time monitoring of COD in CW.

Overall, this study provides further evidence of the potential of waste-filled constructed wetlands for sustainable wastewater treatment. These systems have the potential to effectively remove nutrients from wastewater while also providing a sustainable solution for solid waste disposal.

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References:

Cross, K., Tondera, K., Rizzo, A., Andrews, L., Pucher, B., Istenič, D., Karres, N., McDonald, R., 2021. Nature-Based Solutions for Wastewater Treatment: A Series of Factsheets and Case Studies, IWA Publishing, London.

Liwarska-Bizukojć, E., Chojnacki, J., Klink, M., Olejnik, D., 2018. Effect of the type of the external carbon source on denitrification kinetics of wastewater. Desalination and Water Treatment 101, 143e150, https://doi.org/10.5004/dwt.2018.21758

Mateus, D.M.R., Pinho, H.J.O., 2020. Evaluation of solid waste stratified mixtures as constructed wetland fillers under different operation modes. Journal of Cleaner Production, 253, 119986, https://doi.org/10.1016/j.jclepro.2020.119986

Mateus, D.M.R., Vaz, M.M.N., Pinho, H.J.O., 2012. Fragmented limestone wastes as a constructed wetland substrate for phosphorus removal. Ecological Engineering 41, 65-69, https://doi.org/10.1016/j.ecoleng.2012.01.014

Pinho, H.J.O., Mateus, D.M.R., 2022. Valorisation of solid waste in subsurface flow constructed wetlands based on renewable modular structures: A contribution to a circular economy, In. Circular Economy and Sustainability, Volume 2: Environmental Engineering, A. Stefanakis, I- Nikolaou (Eds.), pp. 215-233, Elsevier, Amsterdam, Netherlands https://doi.org/10.1016/B978-0-12-821664-4.00019-4

Wu, H., Wang, R., Yan, P., Wu, S., Chen, Z., Zhao, Y., Cheng, C., Zhuang, L., Guo, Z., Xie, H., Zhang, J. 2023. Constructed wetlands for pollution control. Nature Reviews Earth and Environment 4, 218–234 . https://doi.org/10.1038/s43017-023-00395-z

Session A5: The impact of urban NBS on public health and well-being

On the integration of nature-based solutions for health and wellbeing in two European Cities: The case studies of Dundalk and Skelleftea.

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ABSTRACT

In an increasingly urbanized world, local governments and international institutions strive to increase the productivity and efficiency of cities, recognized as economic growth hubs, as well as ensures a better quality of life and better living conditions for citizens. Two municipalities that are exposed to diverse climatic conditions and challenges around Europe and have been identified as case studies will be presented.

The first case study is located in Dundalk, Ireland where three Visionary Solutions will be implemented as part of a regeneration project that will assist in the creation of an accessible, safe, green area, through NBS, digital and Socio-cultural interventions.

The first Visionary Solution provides a sheltered outdoor learning pod that is created between Dundalk Library & Museum Quarter, hosts events for target visitors and showcases innovative technologies. Sensors will also be installed to measure the number of visitors and the monitoring improvements to the use of the space. The software for the existing solar panels will enable the energy generated to be displayed by the visitors, encouraging the use of sustainable energy solutions in the area.

The second visionary solution provides enhanced biodiversity through the development of a new sensory garden that complements the existing garden and improves pathways for the public to ensure that visitors have all available opportunities to experience the green spaces and feel their benefits. Sensors will be installed to measure the number of visitors and how long they spend there. Air quality and noise sensors will also be installed, while new touch-screen monitors will display the green learnings.

The final visionary solution provides a new open space for pedestrians and bicyclists with improved cycling infrastructure for visitors to encourage active transportation, reduce air pollution, and support urban regeneration. Specifically, a parking lot will be removed and rezoned to create an area for pedestrians and bicyclists by adding a new bike station in front of the library area. Within the designated cycle space cabling for EV charging points for electric bikes and scooters will be provided, while a bike maintenance area for cyclists will be established. Sensors will be installed to measure the number of cyclists and collect data on air quality and noise pollution.

The second case study involves the conversion of an old landfill into a residential and educational area in Skelleftea, Sweden, using green and digital solutions by implementing five visionary solutions. These solutions will be fully exploited from a digital, nature-based solution (NBS), and socio-cultural perspective.

The first Visionary Solution provides improvements of the waterways in the park, making it more attractive to visitors and nearby residents, encouraging people to spend more time in the park. Visible water also will improve biodiversity and has an educational effect on the public. The improvement of ditches and ponds includes digging out sediments, cutting down vegetation in water channel that connects the two ponds, cutting down vegetation in the ditch upstream from the two ponds, and restoring the ditch by covering the rubber lining with stone material. The solution includes adjustment of the outflow from the second pond. The project also measures water flow and quality by placing measuring devices at four points, as well as incorporating results from existing measuring points (another project).

The second Visionary Solution provides a wetland bed to improve biodiversity. This Solution also includes planting of indigenous species. An inventory of species will be conducted within the pilot area (including invasive species that should be eliminated). Existing flora will be complemented by a selection of indigenous plants. The greater biodiversity will make the park more attractive and the area more functional for the allotments, since pollination will increase. The lower areas of the park will be converted from traditional lawn areas to diverse meadows. In a total area of 1600 + 300 square meters, carefully selected species will be planted or sown, having in mind their characteristics and requirements in terms of wet and moist conditions. Invasive species will be located and eradicated with the method suited to each. A path will be constructed to make the wetland bed more accessible for visitors.

Furthermore, smart lighting in the park provides an inviting environment for the visitors and encourage activities in the park. As Skellefteå is far north, the winter months from late October through March have many hours of darkness, restricting outdoor activities. Smart lighting that promotes activity in the park while reducing light pollution is one way to ensure people still have the possibility to be active outdoors. Giving visitors access to sensors and the lighting itself to improve interactivity and to increase engagement is an interesting option to explore. The number of lighting poles has decreased from the initially 10-15 foreseen, to nine, mainly due to costs. Nine light poles will therefore be installed, incorporating sensors that detect the number of visitors. Other sensors to be applied in the park will measure activities in beehives, availability at the parking-lot, if firewood is available at the barbeque area, the number of visitors in the park, local temperature, wind speed, air humidity, and snow depth. Design and location of the lighting poles has been determined during the co-creation activities.

Information, educational material, and interactive solutions to educate and engage citizens on the solutions in the park are also provided. An information campaign will be addressed to nearby residents, pre-schools, schools, and city residents to impart knowledge about pilot goals, and to enable them to get project updates. Information signs in the park will help engage and educate visitors about the NBS. The strategy for the educational part is to use signs in the pilot area. These signs will inform pre-school/school children and other visitors about why we are letting parts of the lawn transform into wetland beds and connect that information to education about the water cycle and the effects of climate change. There will also be information about the different species in the area, as well as pollinators and why are they important. Later on, there will be information about the recreational area called Vitberget, and for that, a co-creation process will engage the department for recreation.

The last Visionary Solution provides open-air classrooms to young students so that they may receive education in natural settings. It includes creation of space in the park with bee hotels/insect habitats plus building material that students can use to create hotels/habitats, and permanent educational material such as signs about different species. The outdoor classroom has become smaller compared to early visualizations, both due to available land for the purpose and due to costs. The pilot area will have two separate spaces for outdoor learning and playing. One located in the forest between the two ponds will offer seats on tree trunks and will contain a large bee hotel. There will be school material available in boxes that teachers can unlock, as well as building material for making bee/insect hotels. The classroom will have seating places for 25 persons and a table for six. It will be wheelchair accessible. The teachers will be able to connect to power and internet in the outdoor classroom and use the wall to show pictures. This outdoor classroom can also be used outside of school hours by visitors.

The development of these visionary solutions in both pilot sites is approached by following a bottom-up planning and co-design participatory process involving local stakeholders, assuming a "multiple benefits" perspective, and also addressing social issues and cultural diversion. To evaluate the impact of these solutions on various urban challenges, many KPIs are selected and monitored.

Measuring the impact of Nature-Based Solutions on citizens' health and well-being: risks and challenges of using wearable devices

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Keywords: Nature-Based Solutions, wearables, social impact, health, well-being

ABSTRACT

This paper explores the challenges related to the implementation of wearable sensors in the context of smart cities, particularly in the domain of measuring the impact of Nature-Based Solutions on citizens' health and well-being. While opportunities and benefits presented by such technologies are relatively well known and frequently voiced by its manufacturers, this paper's main goal is to highlight the challenges related to the current state and strategies of implementation of such technologies for measuring the impact of Nature-Based Solutions on citizens' health and well-being.

In recent years, we observe a deacceleration of the urbanization rate (from 3.1% in the 1950s to 1.9% in 2020). However, the population of our cities is still growing (UN, 2019) and is predicted to reach 70% of the world population by 2050. This trend is caused by a combination of a positive birth rate in cities, climate and economic migration from rural to urban areas, as well as urbanization of formerly rural areas (Elmqvist et al., 2013). This expansion of urban areas not only affects people but also has negative consequences for the natural ecosystems. That is because cities are great polluters, in terms of heat and CO_2 emission, and they undermine biodiversity through ecosystem degradation (Elmqvist et al., 2013), which negatively affects their resilience to climate change (Chapin, 2000).

The loss of natural resilience to weather extremes, such as floods, heatwaves, windstorms, landslides, droughts, etc., and their frequency due to the climate emergency, has a negative effect on cities' economies and citizens' health and wellbeing (IPCC, 2018; IPBES, 2019). Moreover, because of the climate emergency, many of today's cities have become less sustainable and therefore in need of effective climate adaptation and disaster risk reduction strategies. One promising systemic solution to address these challenges has been bringing nature back to urban areas through so-called green regeneration and resilience thinking for planning (Conti et al., 2021).

The European Commission recognizes and supports such actions under an umbrella concept of Nature-Based Solutions (NBS). By definition, they 'are inspired and supported by nature, cost-effective, and simultaneously provide environmental, social and economic benefits to help build resilience' (Castellari, 2021; p. 17). Nature-Based Solutions may take various forms, for example, pocket parks, green corridors, green bus stops, sustainable drainage systems, retention ponds, etc. As such, they address different climate-related hazards.

The vast body of literature on NBS shows that actions targeted and tailored to specific conditions help to restore biodiversity (Beninde et al., 2015), decrease temperature and pollutants concentration (Ascenso et al., 2021), reduce noise (Dzhambov et al., 2014), and help to manage sewage/gray water (Zhang et al., 2019). However, very often, designers and planners focus only on tackling environmental challenges and, thereby, limit the multifunctional potential of NBS (Bozovic et al., 2017). Nowadays, to show the direct benefits for the local community, NBS must be designed and implemented in a manner that matches the needs of citizens, while simultaneously building the climate resilience of cities (Conti et al., 2021).

As a result, NBSs should, directly and indirectly, affect public health and well-being by creating a healthier environment for citizens. Research shows that the sole presence of green infrastructure has both indirect effects on the life of citizens via building climate resilience and directly affects their health and well-being (Bozovic et al., 2017). In recent years, there has been a growing interest in measuring the impacts of urban blue-green spaces on the health of residents. The literature on the subject shows that living in areas with well-maintained parks decreases the risks of cardiovascular diseases (Mitchell and

Popham, 2008; Gascon et al., 2015), respiratory diseases (Villeneuve et al., 2012), depression (Shanahan et al., 2016), and generally improves mental wellbeing (Alcock et al., 2014; Navarrete-Hernandez, 2019).

While in the scientific literature, one might find a variety of tools being employed for measuring the impact of Nature-Based Solutions on citizens' health and well-being (from more traditional questionnaires, focus groups, or interviews to the usage of ICT tools, like smart bands), on a bigger scale, city managers very often aim to leverage wearable sensors, such as smart bands, equipped with advanced sensing capabilities, to gather meaningful information about people's health or quality of the urban environment. These endeavors very often are made under the framework of sensors-enhanced smart cities (Aivazidou et al., 2021), as they offer a promise of more objective measurements that enable a data-driven decision-making process. Moreover, one can argue that wearable sensors are a crucial part of smart city systems, enabling real-time monitoring of individual and environmental data, advancing personalized services, and efficient resource management, which are the main goals of smart urban development. These devices are also increasingly used in clinical and public health interventions, for early symptom identification, but also performance alerts, and real-time monitoring (Bonato, 2010; Appelboom et al. 2014). While wearable sensors allow for gathering large amounts of objective data regarding health-related parameters and behaviors, the implementation of this technology involves numerous risks and challenges. They need to be carefully addressed, especially if used by public institutions or researchers. Otherwise, the potential of providing benefits to the citizens and communities will not be fully used.

We start the exploration of wearable sensors use by reviewing the existing literature concerning wearable sensor technologies in the smart city context, with a special focus on health and wellbeing-related implementation. We explore the existing risks and potential challenges of integrating wearable sensors into the fabric of smart cities. We focus only on the specific and widely used form of wearable technology, namely smart bands and smartwatches. Because of their accessibility and relatively low costs, they became the main go-to technology in many research projects that aim at measuring the impact of Nature-Based Solutions on citizens' health and well-being.

The integration of wearable sensors into the fabric of smart cities offers immense potential for creating healthier and more livable cities. However, inclusive and fair data collection, citizen engagement, personalized services, and their successful integration require addressing various challenges. Otherwise, technologies underpinning the idea of the smart city might transform our cities into algorithm-managed entities in which citizens are reduced to data points. Based on the literature review, we identified six main challenges: 1) privacy and ethics of sharing sensitive physiological and location data; 2) data ownership and management; 3) data collection and storage; 4) data quality and the accuracy of interpretation; 5) users' acceptance and adaptation; 6) other issues, like cultural barriers, or social exclusion.

The aforementioned categories serve as a framework for presenting specific risks and barriers observed in our case studies -- two EU-funded projects which involve the use of smart bands for enhancing the health of urban citizens. Both projects are focused on implementing Nature-Based Solutions to enable positive changes in terms of urban health and social sustainability (euPOLIS and HEART, funded under Horizon 2020 framework). The HEART project is a health-centered initiative that aims at investigating the benefits of regular visits to green spaces enhanced by Nature-Based Solutions on the health and well-being of patients with a medical history of non-communicable diseases. On the other hand, the euPOLIS project aims to create a methodology that will allow for designing and implementing NBSs, as well as the assessment of their direct and indirect impacts on community health and well-being. In both, part of the evaluation process is done based on the data from commercial wearable devices that cities provide the citizens with.

In both projects, we strive to implement The Civil City Lab Framework (Domaradzka et al., 2022) that emphasizes that a right to a healthy city is immanent for every citizen and urban-space user, regardless of their technological competencies, socio-economic background, education level, gender, age, ethnicity, or religion. Moreover, in euPOLIS, where the infrastructure intervention is planned, we aim to engage participants on every stage of the project, starting from the designing of the intervention to the evaluation of its effects. Our human-centered approach, however, does not exempt us from facing certain challenges and risks related to the involvement of wearable devices.

For health-related projects, Stiglbauer et al.'s (2019) observations are relevant, where they demonstrated that monitoring and quantifying activities are to a small extent beneficial to self-reported well-being and health. The effect of wearing the device was stronger for people who spent more time on the accompanying app. The wristbands themselves did not provide any informative feedback, while the app offered more detailed reports about the recorded activities, completed achievements, and comparisons with peers. Having clear goals and standards and getting feedback on goals and achievements increased self-regulation mechanisms.

However, in the goal-oriented approach, the key factor is the source of these goals, whether it's intrinsic or external. Etkin (2016) showed that when the goal is set externally, the activity measurement might result in less enjoyment and argued it's because participants treated these tasks as work. Consequently, when the monitoring device was removed their engagement in the task decreased as the fun factor was lacking.

Therefore, setting goals with individual citizens must be done according to their capacities. Otherwise, wearing the monitoring devices might have unfavorable effects on the patient's well-being, as unrealistic or unachievable external goals lead to discouragement rather than motivation (Fu et al., 2009; Etkin, 2016). The inability to perform a desirable amount or level of physical activity might result in dissatisfaction, apathy, and lower overall well-being (Maier and Seligman, 2016).

Finally, we conclude by discussing wearable sensor adoption in the context of findings from citizen science literature and highlighting future directions in the integration of sensors into smart cities for assessing the impact of Nature-Based Solutions on citizens' health and well-being. Projects involving wearables fall into a bigger category of citizen science studies, in which data is gathered by citizens in cooperation with professional researchers and analysts. The most common types of citizen science projects are those that involve citizens on a basic level, where their participation is limited to data collection (Bonney et al., 2016). Unfortunately, this is also the case in our two projects as well as the majority of cases described in the literature. In these kinds of projects, the potential of participants is not fully used (Haklay, 2013) and does not contribute to the empowerment of communities. Meanwhile, Shirk and collaborators (2012) have argued that a co-created approach is crucial in the process of building empowered communities.

While ICT tools serve two main functions in many projects: motivational and monitoring, researchers/designers must make sure that they are not an entry barrier for some less tech-savvy participants or the ones that are concerned about data privacy issues and surveillance (Domaradzka et al., 2022; Rychwalska et al., 2022). Therefore, in all such projects, potential participants need to be fully informed about the data collection policy and instructed on the capacities of their devices. That being said, we still see the usage of wearables, accompanying apps, and other ICT tools, like chatbots, as potential concerns. As researchers, we must ensure that wearable sensors empower diverse participation and override social division instead of being entry barriers, as was the case of our two projects. Addressing these concerns requires implementing robust privacy frameworks, data encryption mechanisms, and transparent data handling practices. Furthermore, educating users about the security measures implemented in wearable devices can alleviate privacy concerns and promote user acceptance. Establishing ethical oversight models that respect participants' autonomy could unlock the potential of such smart innovation for wider use in the assessment of the impact of Nature-Based Solutions on citizens' health and well-being (Greshake Tzovaras et al. 2021).

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References:

Aivazidou, E., Banias, G., Lampridi, M., Vasileiadis, G., Anagnostis, A., Papageorgiou, E., Bochtis, D. (2021). Smart Technologies for Sustainable Water Management: An Urban Analysis. *Sustainability*, *13*(24), 13940.

Alcock, I.; White, M.P.; Wheeler, B.W.; Fleming, L.E.; Depledge, M.H. (2014). Longitudinal effects on mental health of moving to greener and less green urban areas. *Environ. Sci. Technol*., *48*, 1247–1255.

Appelboom, G., Camacho, E., Abraham, M. E., Bruce, S. S., Dumont, E. L., Zacharia, B. E., ... Connolly, E. S. (2014). Smart wearable body sensors for patient self-assessment and monitoring. *Archives of public health*, *72*(1), 1-9.

Ascenso, A.; Augusto, B.; Silveira, C.; Rafael, S.; Coelho, S.; Monteiro, A.; Ferreira, J.; Menezes, I.; Roebeling, P.; Miranda, A.I. (2021). Impacts of nature-based solutions on the urban atmospheric environment: A case study for Eindhoven, The Netherlands. *Urban For. Urban Green*, *57*, 126870.

Beninde, J.; Veith, M.; Hochkirch, A. (2015). Biodiversity in cities needs space: A meta-analysis of factors determining intra-urban biodiversity variation. *Ecol. Lett.*, *18*, 581–592.

Bonato, P. (2010). Wearable sensors and systems. From enabling technology to clinical applications. *IEEE Engineering in Medicine and Biol Mag, 29*(3), 25-36.

Bonney, R., Phillips, T. B., Ballard, H. L., & Enck, J. W. (2016). Can citizen science enhance public understanding of science?. *Public understanding of science*, *25*(1), 2-16.

Bozovic, R.; Maksimovic, C.; Mijic, A.; Smoth, K.M.; Suter, I.; Van Reeuwijk, M. (2017). Blue Green Solutions, A Systems Approach to Sustainable, Resilient and Cost-Efficient Urban Development; Climate_KIC, EIT; European Institute for Innovation and Technology: Budapest, Hungary.

Castellari, S.; Zandersen, M.; Davis, M.; Veerkamp, C.; Förster, J.; Marttunen, M.; Mysiak, J.; Vandewalle, M.; Medri, S.; Picatoste, J. (2021). Nature-Based Solutions in Europe Policy, Knowledge and Practice for Climate Change Adaptation and Disaster Risk Reduction; Publications Office of the European Union: Luxembourg, 2021.

Chapin, F., III; Zavaleta, E.S.; Eviner, V.T.; Naylor, R.L.; Vitousek, P.M.; Reynolds, H.L.; Hooper, D.U.; Lavorel, S.; Sala, O.E.; Hobbie, S.E.; et al. (2000). Consequences of changing biodiversity. *Nature*, *405*, 234–242.

Conti, M.E.; Battaglia, M.; Calabrese, M.; Simone, C. (2021). Fostering sustainable cities through resilience thinking: The role of nature-based solutions (NBSs): Lessons learned from two italian case studies. *Sustainability*, *13*, 12875.

Dzhambov, A.M.; Dimitrova, D.D.; Dimitrakova, E.D. (2014). Association between residential greenness and birth weight: Systematic review and meta-analysis. *Urban For. Urban Green.*, *13*, 621–629.

Elmqvist, T.; Fragkias, M.; Goodness, J.; Güneralp, B.; Marcotullio, P.J.; McDonald, R.I.; Parnell, S.; Schewenius, M.; Sendstad, M.; Seto, K.C.; et al. (2013). *Urbanization, Biodiversity And Ecosystem Services: Challenges and Opportunities: A global Assessment*; Springer Nature: Berlin, Germany.

Etkin, J. (2016). The Hidden Cost of Personal Quantification. *Journal of Consumer Research*, *42*(6), 967–984.

Fu, F. Q., Richards, K. A., Jones, E. (2009). The Motivation Hub: Effects of Goal Setting and Self-Efficacy on Effort and New Product Sales. *Journal of Personal Selling & Sales Management*, *29*(3), 277–292.

Gascon, M.; Triguero-Mas, M.; Martinez, D.; Dadvand, P.; Forns, J.; Plasencia, A.; Nieuwenhuijsen, M.J. (2015). Mental health benefits of long-term exposure to residential green and blue spaces: A systematic review. *Int. J. Environ. Res. Public Health*, 12, 4354–4379.

Greshake Tzovaras, B., Senabre Hidalgo, E., Alexiou, K., ... Ball, M. (2021). Using an individual-centered approach to gain insights from wearable data in the quantified flu platform: Netnography study. *J of Medical Internet Research*, *23*(9).

Haklay, M. (2013). *Citizen Science and Volunteered Geographic Information: Overview and Typology of Participation.* In D. Sui, S. Elwood, M. Goodchild (Eds), Crowdsourcing Geographic Knowledge. Springer.

IPBES. (2019). Summary for Policymakers of the Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services; *Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*: Bonn, Germany.

IPCC. (2018). *Global Warming of 1.5 ◦C. An IPCC Special Report on the Impacts of Global Warming of 1.5 ◦C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change*, Sustainable Development, and Efforts to Eradicate Poverty, Intergovernmental Panel on Climate Change: Geneva, Switzerland.

Maier, S. F., Seligman, M. E. P. (2016). Learned helplessness at fifty: Insights from neuroscience. *Psychological Review*, *123*(4), 349–367.

Mitchell, R.; Popham, F. (2008). Effect of exposure to natural environment on health inequalities: An observational population study. *Lancet*, *372*, 1655–1660.

Navarrete-Hernandez, P.; Laffan, K. A. (2019). greener urban environment: Designing green infrastructure interventions to promote citizens' subjective wellbeing. *Landsc. Urban Plan*., *191*, 103618.

Rychwalska, A., Roszczyńska-Kurasińska, M., Domaradzka, A. (2022). *Right to Privacy in the Context of the Privacy Paradox and Data Collection Patterns.* In Proceedings of the 55th HICSS.

Shanahan, D.F.; Bush, R.; Gaston, K.J.; Lin, B.B.; Dean, J.; Barber, E.; Fuller, R.A. (2016). Health benefits from nature experience depend on dose. *Sci. Rep.*, *6*, 285551.

Stiglbauer, B., Weber, S., Batinic, B. (2019). Does your health really benefit from using a self-tracking device? Evidence from a longitudinal randomized control trial. *Computers in Human Behavior*, *94*, 131-139.

United Nations, Department of Economic and Social Affairs, Population Division. (2019). *World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420)*, United Nations: New York, NY, USA.

Villeneuve, P.J.; Jerrett, M.; Su, J.G.; Burnett, R.T.; Chen, H.; Wheeler, A.J.; Goldberg, M.S. (2012). A cohort study relating urban green space with mortality in Ontario, *Canada. Environ. Res*., *115*, 51–58.

Zhang, J.; Zhang, C.; Shi, W.; Fu, Y. (2019). Quantitative evaluation and optimized utilization of water resources-water environment carrying capacity based on nature-based solutions. *J. Hydrol.*, 568, 96–107.

Greenness visibility in urban living environments as pathway to promote health and well-being: mapping spatial differentiation in Flanders (Belgium) based on viewshed analysis.

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ABSTRACT

A growing body of evidence links the presence of green space to positive health effects. For instance a reduction of cardiovascular disease, a superior cognitive and neurological development in children, a better overall mental health or an improved wellbeing and a good physical condition are reported. (Kondo et al., 2018; Lee & Maheswaran, 2010; Maas et al., 2006; WHO Regional Office for Europe, 2016) Not only the presence of dedicated green spaces like parks, nearby forests or natural reserves contribute, also the overall visual contact with greenery is linked to positive effects. Recent Belgian research (Chi et al., 2022) for instance shows a correlation between the presence of large trees and a reduction in sales of mood disorder and cardiovascular medication in urban neighbourhoods. Ensuring an environment with sufficient amount of visual greenery, can therefore be an effective way to contribute to health prevention.

Today both epidemiological research on green space and health, and assessments of availability of green space within spatial planning practice rely mostly on available two-dimensional data such as a Normalised Differential Vegetation Index or spatially explicit land cover data. However the correlation between the amount of greenery observed by people and the amount of greenery measured from a top-down view is proved to be very low or not significant (Jiang et al., 2017; Larkin & Hystad, 2019) Particularly in urban environments buildings can block the sight of greenery. Hence a top-down perspective will overestimate the actual visual exposure to greenery. At the same time a couple of well-placed large trees in a courtyard or narrow street can considerably enhance the local green character, while this effect is underestimated in classic land cover maps. Greenness visibility data should therefore also consider the third dimension to provide a more representative measure of the human-centric observation of greenness.

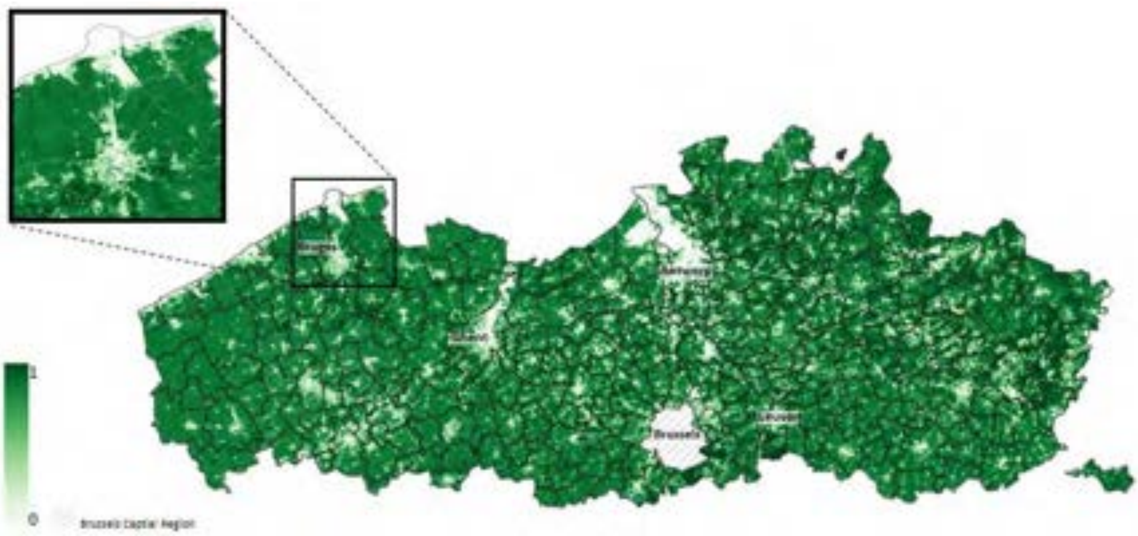
Our research focusses on the development of region-wide datasets on visual green for Flanders (Northern region of Belgium), and a first general assessment of disparities at a regional scale as a starting point for strategic health promoting spatial policy. Furthermore, the data will also be used within a recently started new biomonitoring campaign of the Flemish Environment and Health Study[2].

Visual greenery can be mapped based on photographic material like Google Street View pictures (e.g. Larkin & Hystad (2019)). However, these methods are very time consuming and expensive, especially when mapping a large territory like Flanders (approximately 13522 km²). Also, this methodology only provides data where pictures are available, hence not territory-wide and mostly from locations in the public domain. Therefore our research takes a different approach and draws on the work of Labib, Huck & Lindley (2021), who established a high resolution (5m grid) Viewshed Greenness Visibility Index (VGVI) for the Great Manchester area (UK). In their work Labib et al. (2021) used a viewshed analysis to detect greenness visibility. This is a geospatial technique used to assess the visibility of an area from a specific vantage point. It identifies the portion of the landscape that is visible or obscured from each viewpoint. This analysis can be used to identify areas with greenness visibility, which means assessing where vegetation or green areas are visible or hidden (Petrasova et al., 2015).

[2] https://www.milieu-en-gezondheid.be/en/about-the-center

To perform a viewshed analysis for greenness visibility, different datasets at high resolution are required: a Digital Terrain Model (DTM), containing data on terrain elevation, a Digital Surface Model (DSM) providing data on location and heights of natural and built features, a map indicating the location of vegetated areas. For each possible observer location (i.e., each grid cell), multiple line-of-sights (LOS), in all directions (360° around the observer), are analysed, up to a maximal distance of 800m around the observer. For each line of sight an analysis of greenness visibility is made. Finally, per observation point all different LOS are aggregated to a value between 0 (no green visible, for no LOS) and 1 (100% green visible in every LOS). In the aggregation formula of Labib et al. (2021) visible green elements in close proximity are given more weight in the final score than green elements at a larger distance. For this purpose, a distance decay curve is applied. To establish a VGVI map at (5m grid resolution) for the Greater Manchester area (approximately 1200km²), Labib et al. used almost 87 million observation points, resulting in a calculation time of more than 11 days.

The goal of our research is to calculate a VGVI for the whole region of Flanders (approximately 13.600 km²), using a DTM[3] and DSM[4] (1m and 5m grid), derived from a region-wide LIDAR data campaign in 2015 as input. Although binary vegetation maps are available for more recent years than 2015, the vegetation map of 2015[5] was used to be consistent with the timing of the DTM/DSM. A new LIDAR campaign will probably be organised in the near future, providing recent data sets. In the research we improved the original python code, that was made available by the authors via GitHub[6], in two ways: (1) a correction was made because visible green space below the observer's eye level was not taken into account in a correct manner. In Flanders, a region without large elevation differences, this highly underestimated the greenness visibility in several locations. (2) In order to be able to calculate the VGVI for the whole Flemish region (around 11 times larger than the Greater Manchester area) at a sufficiently high resolution (1 or 5m), some technical adjustments were made to improve computational speed. This included an improved method to parallelise the calculation and avoiding double calculations of overlapping LOS (as also proposed by Brinkmann, et al. (2022)). These technical improvements didn't affect the results of the calculations but decreased the calculation speed to 0.12 milliseconds per observation point (compared to 0.8s per observation point in Labib et al. (2021)), which made it feasible to make calculation for the whole of Flanders within a reasonable time span. Our improved python code will be made available at GitHub shortly.



[3] https://www.vlaanderen.be/datavindplaats/catalogus/hoogte-dtm-0

[4] https://www.vlaanderen.be/datavindplaats/catalogus/hoogte-dsm

[5] https://www.vlaanderen.be/datavindplaats/catalogus/groenkaart-vlaanderen-2015

[6] https://github.com/jonnyhuck/green-visibility-index

Figure 9: VGVI-score for Flanders (2015) - excerpt: Bruges and surroundings: own map.

The resulting VGVI map for Flanders (Figure 9) can be used the assess differences in greenness visibility at a high resolution (1 to 5m grid). From this result, aggregations at larger geographical scales are made to calculate e.g. municipal statistics (e.g. average score per neighbourhood or per municipality).

However not all pixels in the VGVI grid are accessible for everyone, nor will people spend the same amount of time at all locations. Therefore, in the next step of our methodology we derived indicators that are better linked to citizens' actual experiences: (1) a score for every (category of) building, that reflects the view from within dwellings, work locations, healthcare facilities and schools, (2) a score for every public road (where people are able to walk, cycle, …) and (3) an average neighbourhood score (400m catchment area surrounding every dwelling). The VGVI-score per building is calculated as the average score of all VGVI-pixels in a 1m radius surrounding the free façades. The VGVI for road segments is the average score of VGVI-pixels per segment. The neighbourhood VGVI score per dwelling is calculated as the average of all public road segments reachable within 400m.

These scores can be mapped and assessed at different spatial scales (e.g. average VGVI-scores per dwelling per municipality versus analysis of local differentiation of dwelling VGVI-scores), and be related to other spatial challenges. The scores can be supplemented with socio-economic or demographic data to investigate to what extent the territorial differences in greenness visibility (not everyone has a high VGVI-score) also entail aspects of injustice (some social groups have consistently higher or lower scores than other groups). The maps can also be supplemented with data on abundant pavement, linking locations lacking sufficient greenness visibility to potential greening locations. Provided underlying data is updated regularly, also monitoring of changes in VGVI-scores over time is possible, for instance to evaluate the policy goal to combine selective densification with greening interventions. At a project level, the same methodology could be elaborated to a tool for ex ante evaluations of local spatial interventions. By changing DSM and vegetation data, the impact of architectural and landscape design alternatives on the greenness visibility within the project or for the surrounding neighbourhood can be modelled. In this way potential concerns of diminishing greenness visibility can be addressed in a more objective manner. Moreover, it could be utilised as a design tool aimed to maximise the greenness potential of a project. The VGVI scores per building or neighbourhood is also potentially useful information for the real estate market, for instance when used for hedonic price analyses.

The above examples show a broad spectrum of possibilities that the VGVI score offers for spatial policies aimed at strategically improving the visibility of green space as a pathway to health promotion. From a more academic research perspective the VGVI is an improvement to the existing green space indicators, such as NDVI, in terms of assessment of visual exposure at a certain location. Moreover, combined with GPS tracking it could give an indication of dynamic exposures to greenness.

To conclude our research demonstrates that calculating a Viewshed Greenness Visibility Index for a large region is feasible. Furthermore, through also calculating derived indicators that are better linked to citizens' actual experiences, a broad spectrum of possibilities unlocks for improving mental health and well-being in urban areas through strategically enhancing greenness visibility.

REFERENCES

Brinkmann, T.S., Kremer, D., & Walker, B. B. (2022). Modelling eye-level visibility of urban green space: Optimising city-wide point-based viewshed computations through prototyping. *AGILE: GIScience Series*, *Volume 3*(id.27). https://doi.org/10.5194/agile-giss-3-27-2022

Chi, D., Aers, R., Van Nieuwenhuyse, A., Bauwelinck, M., Demoury, C., Plusquin, M., Nawrot, T., Casas, L., & Somers. (2022). Residential Exposure to Urban Trees and Medication Sales for Mood Disorders and Cardiovascular Disease in Brussels, Belgium: An Ecological Study. *Environmental Health Perspectives*, *130*(5). https://doi.org/10.1289/EHP9924

Jiang, B., Deal, B., Pan, H., Larsen, L., Hsieh, C.-H., Chang, C.-Y., & Sullivan, W. C. (2017). Remotely-sensed imagery vs. eye-level photography: Evaluating associations among measurements of tree cover density. *Landscape and Urban Planning*, *157*, 270-281. https://doi.org/10.1016/j.landurbplan.2016.07.010

Kondo, M., Fluehr, J., McKeon, T., & Branas, C. (2018). Urban green space and its impact on human health. *International Journal of Environmental Research and Public Health*, *15*(3). https://doi.org/10.3390/ijerph15030445

Labib, S. M., Huck, J. J., & Lindley, S. (2021). Modelling and mapping eye-level greenness visibility exposure using multi-source data at high spatial resolutions. *Science of The Total Environment*, *755*, 143050. https://doi.org/10.1016/j.scitotenv.2020.143050

Larkin, A., & Hystad, P. (2019). Evaluating street view exposure measures of visible green space for health research. *Journal of Exposure Science & Environmental Epidemiology*, *29*(4), Article 4. https://doi.org/10.1038/s41370-018-0017-1

Lee, A., & Maheswaran, R. (2010). The health benefits of urban green spaces: A review of the evidence. *Journal of Public Health*, *54*(3), 6.

Maas, J., Verheij, R. A., Groenewegen, P. P., de Vries, S., & Spreeuwenberg, P. (2006). Green space, urbanity, and health: How strong is the relation? *Journal of Epidemiology and Community Health*, *60*(7), 587-592. https://doi.org/10.1136/jech.2005.043125

Petrasova, A., Harmon, B., Petras, V., & Mitasova, H. (2015). *Tangible Modeling with Open Source GIS* (1st dr.). Springer Publishing Company, Incorporated.
WHO Regional Office for Europe. (2016). *Urban green spaces and health*.

Urban greenery's effects on Public Health and Wellbeing of Citizens and how to assess it – preliminary euPOLIS findings

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Keywords: urban greenery, urban biodiversity, public health, wellbeing, holistic monitoring

ABSTRACT

Introduction. Many studies report on the ability of natural environments and accessible green and blue spaces in the cities to diminish climate change impacts and lower the possibility of disasters. However, that is not the full extent of their effects. Among others, these urban spaces enhanced with nature-based solutions (NBS) can support active recreation and allow places for relaxation and consolidation from daily stress.

There is some evidence that NBS with their extensive greenery can give the positive impact on numerous psychological and physiological outcomes. Urban areas rich in greenery and biodiversity provide great opportunity for humans to come closer to nature and improve their health and well-being through interaction with a variety of flora and fauna species. Specifically, there is evidence that mental health (anxiety, stress levels) and psychological wellbeing may benefit from plant species richness (Fuller et al., 2007), animal species richness (Dallimer et al., 2012) and soil biodiversity (Wall et al., 2015). Furthermore, it has been shown that soil organisms, through their roles in controlling soil-borne pathogens and pests (soil vitality) lessen the prevalence of allergic diseases (Wall et al. 2015). Replacing or restoring the soil, regulation of water conditions, enabling plant species diversity - especially native ones, can substantially increase soil biodiversity leading to recovery of the natural soil food web, so the pathogen risk would be minimized with respect to communicable and non-communicable diseases (Crump et al., 2021). However, urban green spaces can also be linked to negative health outcomes, such as allergic reactions, or vector-borne diseases, as the result of increased exposure to allergenic pollen or increased amount of disease vectors in urban green environments (Calaza-Martinez and Iglesias-Díaz, 2016). These potential harmful effects may be addressed through the adequate design, maintenance and management of urban green spaces and selection of species.

Although different studies show some positive (or negative) effects of NBS on public health and wellbeing (PH&WB), still it is a challenge to actually quantify the extent of the effects, and also attribute the quantity to particular characteristics of an NBS. This is why EC has established a call topic SC5-14-2019 - Visionary and integrated solutions to improve well-being and health in cities, to fund projects that will implement different types of solutions that are capable of enhancing PH&WB in cities and assess their impacts. Once demonstration sites are developed and assessed, key findings and indicators will be included in the already available EC Handbook of indicators - Evaluating the impact of nature-based solutions: A handbook for practitioners.

This paper presents preliminary findings in the endeavour to quantify urban greenery's and biodiversity's effects on PH&WB, by integrating subjective, objective, physiological, and psychological monitoring approaches and producing a multifaceted understanding that is essential for policymakers, urban planners, and public health professionals to design sustainable and nature-inclusive cities that promote the well-being of their inhabitants.

Methods&Materials. Understanding the extent of urban greenery's (and biodiversity's) effects on PH&WB requires a comprehensive approach that covers different monitoring aspects. By combining subjective, objective, physiological, and psychological assessments (Figure 10), it is possible to gain a holistic understanding of these effects. **Subjective** assessments involve gathering information directly from

individuals through questionnaires or surveys. These tools can capture people's perceptions, attitudes, and experiences related to urban biodiversity and its impact on their PH&WB. Questions may focus on aspects such as stress levels, mood, overall satisfaction, and perceived benefits or drawbacks of biodiversity in urban areas. It should be noted that results of these assessments are correlated with the extent of participant's prior knowledge on greenery or biodiversity and relations between greenery & biodiversity and PH&WB. **Objective** assessments involve conducting field studies to observe and measure various aspects of urban greenery & biodiversity (e.g., species richness – birds, butterflies, plants, habitat quality and diversity, blue space availability, connectivity, and accessibility of urban green spaces, etc.) and their potential influence on public health. These studies typically involve trained researchers or experts who collect data on parameters such as species diversity, abundance, and ecological interactions. By analysing these objective measures, it is possible to understand the direct and indirect impacts of greenery & biodiversity on factors like air quality, noise reduction, temperature regulation, and natural spaces for physical activity. Monitoring **physiological** effects through smart wearables offers a more detailed understanding of how urban biodiversity affects individuals on a biological level. "euPOLIS by BioAssist" (Gallos et al., 2022) is an interactive health-centric platform developed in the euPOLIS project, that is compatible with multiple commercial smart bracelets that provides accurate recordings of physiological parameters (skin temperature, pulse, oxygenation and/or respiration), levels of physical activity (intensity and duration), sleep quality and user interactive feedback, and can provide inputs for physiological monitoring. This data can provide valuable insights into the immediate and long-term impacts of greenery & biodiversity on physical health. In addition to physiological effects, proprietary smart wearables can provide insights into **psychological** well-being. Feel Data Monitoring Device (along with Feel Data Monitoring platform by SentioLabs) for monitoring and assessment of the emotional status and stress/anxiety levels is another source of bio-signal data in the euPOLIS project, that provides inputs on psychological responses to implemented NBS interventions. The Feel Emotion Sensor is a wristband that has integrated bio-sensors which monitor a variety of end user physiological signals throughout the day, while in the background, proprietary advanced algorithms analyse these signals to recognize the wearer's emotions.

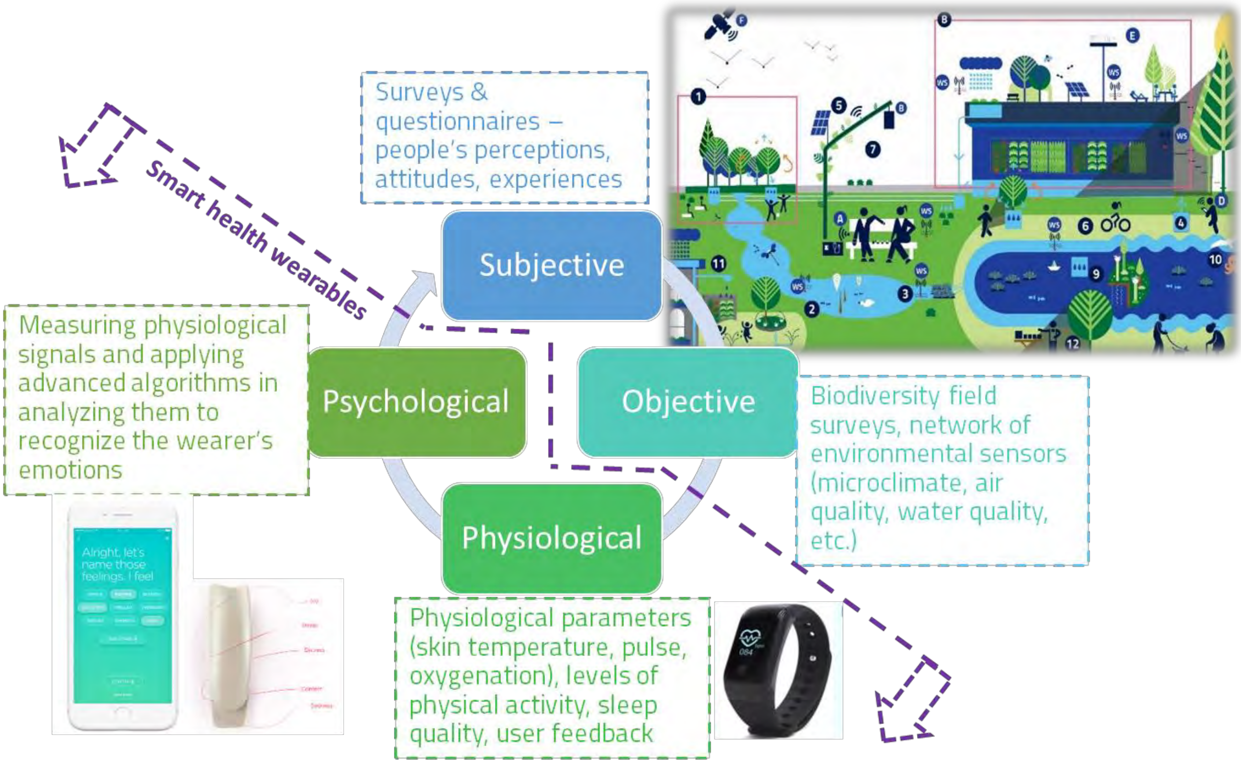

Figure 10 Subjective, Objective, Physiological, and Psychological assessments to gain a holistic understanding of the extent of greenery's and biodiversity's effects on PH&WB

All the different aspects of monitoring need to be performed before and after the implementation of NBS, and depending on the actual type of data can be of a sub-daily or daily timestep or be static. The data gathered from multiple types of smart health wearables is collected from a diverse group of volunteers, with a sub-daily timestep, and statistically analysed for peaks, trends, and inconsistencies to showcase the impact of NBS (by comparing the “before” and “after”).

Case studies. euPOLIS case studies include 4 front-runner cities of different sizes in different biogeographical and climatic regions in which NBS are designed and tailored to each urban environment characteristics and challenges (Belgrade in Serbia, Piraeus in Greece, Łódź in Poland and Gladsaxe in Denmark). There are also five follower cities (Palermo in Italy, Limassol in Cyprus, Trebinje in Bosnia & Herzegovina, Bogota in Colombia, Fengxi in China), that are getting the knowledge and experience about planning of NBS from the front-runner cities, but also participate in mentoring sessions for replication of socio-cultural-urban hubs.

The clusters of NBS which are designed and implemented (under different scales) in the front-runner cities include: (1) NBS-based multifunctional pocket parks accessed by NBS locally conditioned pathways and shared spaces, (2) Waterways with mini biotope nodes, aquatic biodiversity – feed from groundwater aquifer or purified surface runoff, (3) NBS for surface runoff quality and pluvial flood management, (4) Groundwater abstraction for water, energy, greenery nexus, (5) MF NBS canopy for socializing, „recharging electronics“, or „green bus stop“ etc., (6) Multi-functional Live vegetation shaded waterfront promenade, (7) Air pollution abatement shrubs, trees and vertical green curtains, (8) Urban Metabolic hub with multi-functional ecotechnology demonstration/promotion, roof garden and art/cultural performance, (9) Multi-functional floating island, river water purification, (10) Coastal sea bottom marine aquatic biotope with euPOLIS-NBS, (11) Multi-functional euPOLIS Urban square/streetscape and other NBS (biotopes, sensory garden, waterfall, biodiversity & kitchen garden for socialising, recreation), and (12) Space for NBS business activation and promotion.

The most notable expected impacts of different NBS clusters on PH&WB include improvements of microclimatic conditions, air, water and soil quality, reduction of noise, increase of greenery and socializing spaces and changes in biodiversity, resulting in the reduction of the number of risk factors for non-communicable diseases (obesity, depression, stress, cardiovascular, etc.), increased duration and quality of physical activities, enhanced overall PH&WB stemming from the positive aesthetic experience and pleasure created in contact with visual attraction of dryland/marine aquatic interaction, stimulated relaxation and restoration, etc. A whole array of improvements can be attributed to augmentation of the use of NBS-enhanced public space on continuous basis, increasing the number of citizens of all ages in outdoor activities and interactions, create positive emotional attachment to the neighbourhood resulting in WB enhancement and improved socializing (improving space friendliness, safety, sense of ownership of the public space and sense of belonging to the community, community social cohesion, inclusivity, building trust in the decision-making process by being part of the process, etc.). The interplay of different effects of a particular NBS, and demonstration sites as a whole, together with their effects on the whole neighbourhood (and finding the extent of a “neighbourhood”) is one the main tasks of euPOLIS and its assessment methods (see Baki et al., 2023 for more details on the setup of the euPOLIS assessment framework).

Future work. The project is currently in its implementation phase, with a focus on deploying a comprehensive monitoring system (network of sensors, smart wearables, remote sensing, digital and analog people and field surveys, workshops, interviews, etc.) and constructing NBS within the urban environment. This phase aims to collect valuable data and assess the effectiveness of NBS in enhancing public health and wellbeing. While progress is being made, it is important to acknowledge that determining the precise extent to which specific NBS characteristics contribute to these enhancements remains a task for further investigation. This attribution process will involve statistical analyses, modelling, and advanced data interpretation techniques. It requires a multidisciplinary approach involving environmental scientists, urban planners, public health experts, and social researchers, among others. Ultimately, the determination of the extent to which specific NBS characteristics contribute to enhancements in public health and wellbeing will provide valuable evidence for policymakers, urban planners, and stakeholders. This knowledge will guide future decision-making processes regarding the design and implementation of NBS, ensuring that they are optimized to create sustainable, healthy, and resilient urban environments.

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References:

Baki, S., Randelovic, A., Kazantzi, A., Stanic, F., Makropoulos, C., 2023. A glimpse into the euPOLIS multi-dimensional Indicator System for Site Screening & NBS Assessment. Internation Conference of the International Ecological Engineering Society, Chania, October 1-5 2023.

Calaza-Martinez, P., Iglesias-Díaz, I., 2016. The risk of urban trees. Concept, context and evaluation (In Spanish) Madrid, Spain.

Crump, L., Martinoli, D., Zinsstag, J., 2021. Links between biodiversity and human infectious and non-communicable diseases: a review. Swiss Med Wkly. 2021 Mar 28;151:w20485. doi: 10.4414/smw.2021.20485. PMID: 33873205

Dallimer, M., Irvine, K.N., Skinner, A.M.J., Davies Z.G., Rouquette J.R., Maltby L.L., Warren P.H., Armsworth P.R., Gaston K.J., 2012. Biodiversity and the Feel-Good Factor: Understanding Associations between Self-Reported Human Well-being and Species Richness. BioScience, 62(1), 47–55, https://doi.org/10.1525/bio.2012.62.1.9

Fuller, R.A, Irvine, K.N, Devine-Wright, P., Warren, P.H, Gaston, K.J., 2007. Psychological benefits of greenspace increase with biodiversity. Biol. Lett., 3390–394, http://doi.org/10.1098/rsbl.2007.0149

Gallos, P., Menychtas, A., Panagopoulos, C., Protopapadakis, E., Doulamis, N., Doulamis, A., Sardis, E., Bimpas, M., Kaselimi, M., Maglogiannis, I., 2022. Designing a Cloud Based Platform for Monitoring Well-Being and Public Health in Areas with Natural Based Solutions. In: Perakovic, D., Knapcikova, L. (eds) Future Access Enablers for Ubiquitous and Intelligent Infrastructures. FABULOUS 2022. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, vol 445. Springer, Cham. https://doi.org/10.1007/978-3-031-15101-9_7

Wall, D., Nielsen, U., Six, J., 2015. Soil biodiversity and human health. Nature 528, 69–76 https://doi.org/10.1038/nature15744

Innovative urban solutions to enhance public spaces and promote good public health and wellbeing - the case studies of euPOLIS and VARCITIES

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ABSTRACT

Introduction. In recent years, the rapid growth of urbanization has presented numerous challenges for cities around the world due to global geopolitical, economical, climate and other factors. One of the critical areas of concern is the pressure on urban areas to provide environments to support good public health and wellbeing (PH&WB). As cities become denser and more crowded, there is an increasing demand for innovative urban solutions that prioritize the physical and mental health of residents. Public spaces play a vital role in urban life, serving as gathering places, recreation areas, and cultural hubs, even when they are not green (as long as they are safe) (Holy-Hasted and Burchell, 2022). However, they are often underutilized or poorly designed, failing to meet the diverse needs and aspirations of urban populations. Furthermore, the rise of sedentary lifestyles, pollution, and stress-related illnesses necessitates a rethinking of urban environments to prioritize the wellbeing of citizens and stepping away from traditional for-profit urban planning. This need has given rise to a wave of innovative urban solutions aimed at transforming public spaces into healthier and more inviting, vibrant places. These solutions combine technology, design principles, and community engagement to create environments that sustain physical activity, social interaction, and mental rejuvenation. Some examples of such solutions may include: (1) development of infrastructure to encourage active transport (cycling and walking), which promotes physical activity (Nieuwenhuijsen and Khreis, 2016), (2) increasing access and quality of urban green spaces, which provides better (microclimatic) conditions and opportunities for physical activities, social interaction and relaxation, and additionally can mitigate pollution levels (WHO, 2016), (3) supporting urban farming and gardening to provide citizens with option of sustainable and healthy food productions, but also fosters a sense of community and connectedness to nature (Audate et al., 2019), and (4) introduction of digital health technologies, either as digital platforms or smart health wearables (Gallos et al., 2022), that actually provide citizens with means to track and manage their health more actively, and can be integrated with additional relevant data (e.g. air quality, noise levels, etc.) for a holistic assessment of health conditions.

euPOLIS and VARCITIES are projects aimed at creating public spaces by using different types of innovative urban solutions that support good PH&WB of citizens, inclusivity, social cohesion, place attachment, and ownership of the space, which in long-term provides sustainability of solutions (Domaradzka et al., 2022). euPOLIS' aim is to provide a planning methodology that delivers the best services of nature-based solutions (NBS) to address citizens needs for improvement of PH&WB in open public spaces. This includes systematic deployment of multi-functional natural systems to simultaneously enhance PH&WB, provide resilient urban ecosystem services, regenerate urban ecosystems, improve urban biodiversity, resilience to climate change, extreme events, water-stress, pollution, create inclusive and accessible urban spaces, etc. The extent of euPOLIS NBS interventions for each of the demonstration sites is selected together with

stakeholders (experts, local authorities, NGOs, citizens, etc.) through euPOLIS participatory processes, aimed at establishing good diversity and inclusivity of participants, and suited to local needs. The vision of VARCITIES is to implement real, visionary ideas and add value by establishing sustainable models for increasing the health and well-being of citizens: women, children, young people, middle aged, and the elderly, who are exposed to diverse climatic conditions and challenges in and around Europe. VARCITIES sets the ambitious target to advance innovation across different urban scales by fully exploiting nature-based solutions from a digital, social and cultural perspective. Public spaces are envisioned as people-centered areas that support creativity, inclusivity, health, and happiness for the citizens. The overarching philosophy behind VARCITIES is the co-creative process.

Both projects cover a wide range of topics and urban environments and aim at developing greener, more sustainable European cities for all their inhabitants, stressing out the chance to work with NBS and green policies to eventually deliver a positive outcome for the citizens. In this work we aim to briefly outline the differences and similarities between the two projects with an ultimate goal to provide a set of guidelines for future implementations.

Case studies. The case studies in euPOLIS encompass four leading cities, each differing in size, located in various biogeographical and climatic regions. In these cities, NBS are specifically designed and customized to suit the unique characteristics and challenges of their respective urban environments. The front-runner cities are Belgrade in Serbia, Piraeus in Greece, Łódź in Poland, and Gladsaxe in Denmark. Additionally, there are five follower cities, namely Palermo in Italy, Limassol in Cyprus, Trebinje in Bosnia & Herzegovina, Bogota in Colombia, and Fengxi in China. These follower cities are actively acquiring knowledge and experience from the front-runner cities regarding NBS planning and monitoring. Moreover, they participate in mentoring sessions focused on replicating socio-cultural-urban hubs, thereby contributing to the dissemination of expertise and fostering collaboration. VARCITIES has identified seven European municipalities as the Pilot Cities of the project. Integrated and sustainable initiatives are created that increase the health and well-being of citizens, supporting both municipal actions and local SMEs in meeting credible opportunities to grow and generate revenues. Each Pilot City has identified a pilot site for implementing local actions. The seven Pilot Cities are: Castelfranco Veneto (Italy), Chania (Greece), Dundalk (Ireland), Gzira (Malta), Leuven (Belgium), Novo mesto (Slovenia) and Skellefteå (Sweden). These cities differ in geography, climate conditions and the challenges they face, but share the same vision of a healthier and sustainable urban future.

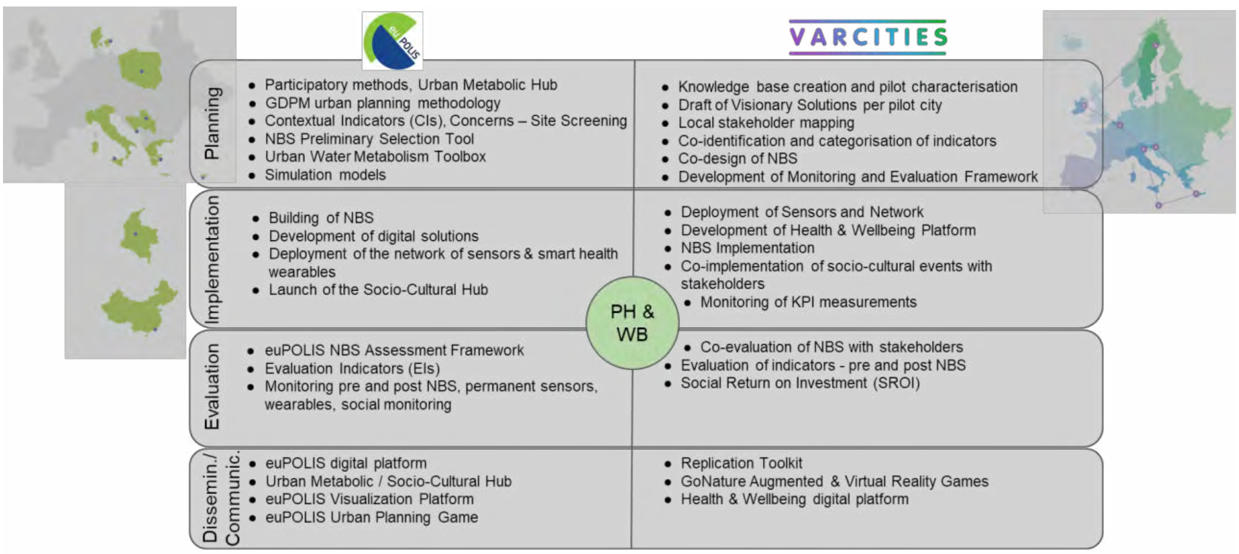

Figure 11 Overview of four distinctive phases in the two projects centred around enhancement of PH&WB

The common processes of the project. Both projects share similar phases that include planning, implementation, evaluation and communication & dissemination (Figure 11). In the **planning** phase, various preparatory actions are taken, including stakeholder identification, establishment of a baseline, site screening to identify key concerns, co-creation of innovative urban solutions, and joint development of indicators. The actual procedures and tools with which such processes are performed differ among the project, so that euPOLIS sets a more systematic multi-disciplinary criteria for planning (including tools for preliminary selection of NBS), whereas VARCITIES focuses more on systematic criteria for mapping and interaction with different types of stakeholders. During the **implementation** phase, projects proceed with the deployment of solutions formulated during the planning phase. Furthermore, efforts are focused on the development of digital solutions such as health platforms and/or wearables, aimed at empowering citizens to actively monitor their own health and well-being. euPOLIS platform is compatible with commercial smart watches, and additionally the project uses proprietary Feel sensor for measuring emotional response of wearers. VARCITIES Health and Wellbeing (H&WB) platform contains four different types of dashboards that have been specified to enable engagement with a broad range of stakeholders and does not use wearables but collects user experiences through the platform. The implementation phase involves the comprehensive deployment of integrated monitoring systems by both projects, enabling the quantification of indicators. Additionally, both projects work on implementing socio-cultural solutions, albeit utilizing different methods and approaches. The **evaluation** phase, combined with **communication and dissemination** efforts, holds the most valuable outputs for the wider scientific and practitioner community. It is during this phase that both projects analyse the collected data, extract key findings, and derive take-home messages. These findings not only contribute to the knowledge base but also provide instructions for replication and upscaling. Some of the solutions in use here are digital platforms, serious gaming, powerful visualization tools, and in the background various statistical analyses, modelling, and advanced data interpretation techniques are employed. This process necessitates a multidisciplinary approach, involving experts from fields such as environmental engineering and science, urban planning, public health, social research, and more. Ultimately, the assessment of how specific characteristics of NBS contribute to improvements in public health and well-being will provide valuable evidence for policymakers, urban planners, and stakeholders.

Innovative urban solutions.

euPOLIS innovative people-centric urban planning methodology is developed, tested, and implemented in the previously mentioned four front-runner cities. Using the urban planning methodology and participatory processes, different types of NBS, together with digital and social innovations, are implemented on demo-sites. NBS are designed to improve (among others) outdoor environmental conditions (micro-climate) at the sites of interest, by increasing greenery (quantity, quality, access), and with-it biodiversity, introducing paths for active transportation, urban gardens and farms, implementing climate-resilience enhancing NBS, all supporting and promoting increased physical activity of citizens as a precursor for health and well-being enhancements. These preliminary studies aim to also provide the methodological framework for monitoring future socio-cultural and business improvements in the areas of interest. The solutions are then implemented and constructed, and carefully monitored before, under and after construction to provide an evidence-based assessment of their multidimensional impacts.

The VARCITIES project prioritizes an integrative, trans-disciplinary focus that considers the entire ecosystem in all of its complexity, including all members of society from various personal and social backgrounds, as well as the necessity for nature-based approaches to be individual and context specific. For this reason, each Pilot City is directly informed by the unique and respective needs of the local society, the specific contextual evolution and the proposed solutions are in line with the strategic municipal policies. VARCITIES actions aim to deliver a multitude of interventions, methods and innovative practices based on a PH&WB platform, measurement framework, and methodology, supported by customizable and extendable plugin solutions. A co-creation strategy is also being implemented to involve local experts and citizens in the process. NBS interventions aim at becoming an underlying customizable fabric of an entire ecosystem of fully connected intelligent sensors and devices, capable of delivering several co-benefits, thus transforming the daily lives of European citizens.

How to track innovative urban solutions. The euPOLIS indicator framework provides support for the planning of NBS along with their monitoring during deployment and exploitation and includes two distinct levels of indicators: (1) Contextual and (2) Evaluation Indicators, which both come from five categories covering direct and indirect effects of solutions on PH&WB (PH&WB, environmental, social, economic, urban development categories). Contextual indicators are quantified from readily available data (including stakeholders) and are used to identify main concerns on the site, set goals and targets, and find most suitable solutions to address these concerns (Baki et al., 2023). Evaluation indicators are for assessing NBS impacts, and use data from different types of sources all feeding into the euPOLIS cloud DMS: network of LoRaWAN sensors for environmental data, remote sensed data, surveys and questionnaires, field biodiversity surveys, health wearables, euPOLIS digital platform, etc. Advanced visualization methods are used to show data to the citizens in near real-time, so that they can, together with data from health wearables, have the most informative overview of their individual but also site health conditions. To furthermore promote citizen science, and enable co-creation, euPOLIS develops an urban planning serious gaming tool. Additionally, there is a set of the KPIs which aggregate data across different levels and categories of information to provide an overall project evaluation. In VARCITIES, any NBS directed towards a given challenge is associated with a set of objectives and actions, which in turn are associated with expected impacts. For the monitoring and evaluation framework a list of Key Performance Indicators (KPIs) that are measured together with useful details about each pilot, has been created. Various methodologies are used to gather information about the KPIs calculation. Specifically, air quality, microclimate conditions, noise levels, and the number of visitors in public green spaces are all tracked in real-time using data from sensors. Through the survey page of the H&WB platform, self-perceived health and wellbeing data and perceptions of urban nature are gathered, while statistical data for each KPI extracted by local databases, citizen observatories, GEOSS, and EUROSTAT are used to give citizens helpful information about their wellbeing. A network of sensors is established and linked with a cloud-based ICT H&WB platform that is developed. Data from sensors is visualized on standard displays but also on mobile platforms. The collected data is also fed and displayed on the H&WB platform. Moreover, local data platforms are implemented in order to establish a framework for data management. A REST API releases data derived from the local data platforms to the H&WB visualization platform. Mixed reality (MR) applications are also employed to engage with citizens and increase environmental awareness.

Future work. The primary objective is to consolidate knowledge and evidence from both projects and integrate them into a unified/common indicator framework. This framework can then be incorporated into the EC Handbook on indicators, serving as a valuable resource to practitioners in evaluating NBS.

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References:

Audate, P.P., Fernandez, M.A., Cloutier, G., Lebel, A., 2019. Scoping review of the impacts of urban agriculture on the determinants of health. BMC Public Health 19, 672 https://doi.org/10.1186/s12889-019-6885-z

Baki, S., Kazantzi, A., Makropoulos, C. 2023. NBS efficiency-informed urban upscaling methodology: the euPOLIS approach. EGU General Assembly 2023, Vienna, Austria, 24–28 Apr 2023, EGU23-17125, https://doi.org/10.5194/egusphere-egu23-17125

Domaradzka, A., Biesaga, M., Domaradzka, E., Kołodziejczyk, M., 2022. The Civil City Framework for the Implementation of Nature-Based Smart Innovations: Right to a Healthy City Perspective, Sustainability 14, no. 16: 9887. https://doi.org/10.3390/su14169887

Gallos, P., Menychtas, A., Panagopoulos, C., Protopapadakis, E., Doulamis, N., Doulamis, A., Sardis, E., Bimpas, M., Kaselimi, M., Maglogiannis, I., 2022. Designing a Cloud Based Platform for Monitoring Well-Being and Public Health in Areas with Natural Based Solutions. In: Perakovic, D., Knapcikova, L. (eds) Future Access Enablers for Ubiquitous and Intelligent Infrastructures. FABULOUS 2022. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, vol 445. Springer, Cham. https://doi.org/10.1007/978-3-031-15101-9_7

Holy-Hasted, W., Burchell, B., 2022. Does public space have to be green to improve well-being? An analysis of public space across Greater London and its association to subjective well-being, Cities, Volume 125, 103569, https://doi.org/10.1016/j.cities.2022.103569.

Nieuwenhuijsen, M.J., Khreis, H., 2016. Car free cities: Pathway to healthy urban living, Environment International, 94, pp. 251 - 262, https://doi.org/10.1016/j.envint.2016.05.032

World Health Organization, 2016. Urban green spaces and health. World Health Organization. Regional Office for Europe. https://apps.who.int/iris/handle/10665/345751

Session A6: Circular design for increased resilience I

Bioregional approach for circular design: case study in Roma via Guido Reni (Italy)

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Keywords: Bioregional approach, resilience, circular design, community and laboratory centre

ABSTRACT

Introduction

A palpable chance of linking together a great number of issues, which are nowadays likewise goals for overcoming the environmental-social derangement of our present human condition in the world, can start out from the ideal and well-known harmony between place, time and nature. How to design with circular economy principles in the XXI century? The ancient Greek philosopher Aristotle had coined the three categories of "*space, time and action*"; they can be interpreted as goals of the present time: space as respect of the place, attention to resources and energy saving; time as lasting property of goods and products, by means of a cared design and recycling actions, thus taking into account life cycle and efficiency; and finally the action, i.e. the architecture and construction as mediator between nature and needs: through circular methodologies and bioregional strategies. This is translated into practice by means of the generation of a harmony between indoor and outdoor arranged with technologies and materials at high level of naturality. In a few words through a bioregional approach. [1]

However, living beings – including humans – have been provided with an important character, the resilience, which helps to actually adapt life procedure and welfare to the environment even when dealing with very seriously hazardous conditions. The definition of resilience, when applied to man, can be synthesized in the "… capacity and dynamic process of adaptively overcoming stress and adversity while maintaining normal psychological and physical functioning." [2] Therefore even the Nature's strength and phenomena are faced and controlled, either by employing the resilience or by contrasting the environmental conditions and thus greatly modifying as many as possible elements, so as to become "perfect" for human habitat. As far as the natural resilience is concerned, the adaptation occurred very frequently during man's life on Earth, but only lately the term has been borrowed from natural science and ecology, with the aim of defining a possible future behavior of humanity in a scenario suitable for contrasting the highly negative effects of Global Climate Change.[3]

Applying this concept to design, a peculiar methodology will allow a use destination matching as much as possible with the identity of the bioregion in terms of both anthropic and natural values.

"A bioregion anchors humans within living systems through shared space and resources. It acknowledges that human habitats are more than skyscrapers and boulevards. They are extensions of watersheds, foodsheds, fibre sheds, and food systems. Living beings are what forge relationships between the city and natural systems, and are integral parts of a bioregion." [4]

Resilience is considered actually relevant into a process when it includes the chance for user and citizens to have a different behaviour which can be stimulated by the new architecture of the place. [5] "Individually we can all immediately adopt and advocate for system structures that conform to the needs of the environment that sustains us: local regenerative agriculture, good public transit that eliminates the need for private cars, making our own entertainment, making and fixing things, and using public resources like libraries and community centres … Centring practices support being able to respond with compassion and care instead of anger or frustration." [6]

Methodology

The first goal of a bioregional project is that of applying a procedure for design with a sound establishment of investigations upon the context, the environment, the natural and cultural resources: these are aimed at creating a background of knowledge about the bioregion, so as to understand both: the anthropic/natural potentials and the elements to be safeguarded. (Natural resources: biotic and abiotic, energy, prime matter, water, soil; anthropic resources: wastes, existing constructions, traditions, craftmanship, material culture, art, society, religion … etc)

After the information data have been gathered and a knowledge frame has been created, the design process will proceed as much respectful as possible of the existing asset and environmental elements, by including in the choices both flora and fauna, and improving the quality of life for users and citizens. Being in a large and historically consolidated city as Rome, but in a modern district, the cultural heritage, traditions and expression are safeguarded and taken into account, as part of the anthropic environment.

Expected result

The research about design actions by means of a bioregional strategy will be outcome with a project which will make an attempt to propose a circular approach to the architecture in existing cities. Exploitation of natural energy sources: sun, wind, vegetation, water, soil, respect of the existing cultural area are the main issues to be applied: this procedure will generate a potential for resilience, first of all by including a wide garden and a lot of trees, which will produce oxygen for counteracting carbon emissions, and also with the potential defined by the dissemination of natural fibre-composed new products for architecture and general constructions.

Case study: description of the existing context, potential and critical points

The selected district (Flaminio) for testing the aforesaid design methodology is located in the north area of Rome, within the left bight of the Tiber River, surrounded by the hills, Villa Borghese, Parioli mounts, Mario mount and villa Glori, identified by the axis of via Flaminia between Milvio bridge and “Porta del Popolo”. It has always been considered as the sporting-cultural site of the city.

The present Municipality [7] required for the area - once being military barracks, named Guido Reni after the well-known Italian painter and engraver - that it should become the venue for a “Science City,” which could host new facilities to citizens and trying to generate a contribution for economic, social and cultural growth of the district Flaminio, in which it is located.

In the here proposed research a number of potential issues and some critical points will be outlined, so as to exploit the positive resources and to safeguard the weaknesses, aiming at improving the circular processes and thus facilitate the growth of resilient habits and practices.

Project: Design choices for improvement of resilient practices in the area

In the actual site of the project (fig.1) the chosen use destination for the new building, which has to respect both the administrative – mandatory and advised – restrictions, will be that of a Laboratory establishment working on technological innovation for materials at high level of naturality; the strategies and the selection of construction methods and techniques will be in accordance with the goal of the Laboratory itself, so it will employ hemp and lime bricks as main wall-filling material. Moreover the outdoor spaces, arranged as a common good, so accessible to all citizens, will include also an area, occupied by some textile natural plants, which could be employed for the laboratory testing procedures on the way of creating innovative construction products at high level of naturality.

Fig. 1 The site for the circular project

"… in a present in which we live without being able to restore any primitive condition of uncultivated naturality, since we have to continue to act projectually according to the conscience, we can only take the road kept by nature. It has to do with pursuing a conscious projectuality, by providing such a definition to things' projectual order towards nature, that can feed the individual evolution simultaneously respecting the vital complexity." [8]

The scientific research laboratory will host also some community activities, so opening to the city different spaces: the trees and dehors for the shading in summer and the resting areas with solar gains in winter, due to the selection of specific vegetation, which, being deciduous, will be a support for both the seasons; the external gardens with perfumed species and beautiful flowers in various seasonal moments, and the actual chance of visiting the innovation systems which will be developed indoor.

"Creation of shapes depends on the genetic process in virtue of which the humanity itself participate to the cosmic creation of world … Nature modification for human goals is directed to a progressive transformation of physical space from a natural state to an anthropic state. … In nature, shape is (in fact) the result of the arrangement of manifold single data of the space, according to the life evolution and to individual and global efficiency." [7]

Conclusion

The proposed study will try to demonstrate how the innovation and the respect for the history and contextual identity of a district, included in a peculiar bioregion, could harmonise and generate a sustainable model of architecture and circular economy, which could contribute to promote environmentally conscious and resilient behaviour within users and citizens.

References

[1] Buoninconti L., De Joanna P., Falotico A. (2020) Bioregionalismo ed edilizia sostenibile, Luciano editore, Napoli.

[2] Russo, S.J., Murrough, J.W., Han, M.H., Charney & D. S., and Nestler, E.J. (2012). "Neurobiology of resilience". Nat. Neurosci. 15

[3] Amitav, G. (2016). The great derangement. The university of Chicago Press, USA

[4] Gattupalli Ankitha (2023) Circular economy: designing for bioregions, in http:// www. archdaily.com (download on May 2023)

[5] Holling C. S. (1976) Resilience and Stability of ecosystem. In: Jantsch E., Waddington C. H., (Eds) Evolution and consciousness: human systems in transition, Reading, Mass.: Addison-Wesley.).
[6] Cone L. (2023) Seeing more clearly. In: Resilience.org / https://www.resilience.org/stories/2023-05-22/seeing-more-clearly/ (download on June 2023)
[7] http://www.urbanistica.comune.roma.it/news-edilizia/26-dipartimento/ trasformazione/uo-riqual-urbana/350-stabilimento-militare-materiali-elettrici-di-precisione.html
[8] Haring H, (1982) Das andere bauen. Gedanken und Zeichnungen, Verlag, Stuttgart.
[9] Van der Ryn S., Cowan S., (1995), Ecological Design, Washington, Island Press.
[10] Francese, D. (2016). Technologies for Sustainable Urban Design and Bioregionalist Regeneration. Routledge: UK

El Remanso Experimental Center in Choachí-Colombia, A laboratory Eco-Village to learn and co-build.

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Keywords: bioconstruction, bioprospection, circular bioeconomy, degrowth, decarbonization

ABSTRACT

The purpose of the present research was to advance in the implementation of an Eco-Village that incorporated elements of bioconstruction with the use of guadua cane framed in a circular design and integrated planning approaches for increased resilience in an area of high seismic risk in the Andes Mountains of Colombia. Likewise, it included energy transition elements advancing towards decarbonization with the use of solar panels for electricity generation and water heating. Similarly, it integrated clean production linked to regenerative agriculture and circular bioeconomy using closed water circuits from bioprospection purification processes in internal treatment plants, equally, waterless toilets that allow the use of human waste as an input for composting and urine mixed with water for nitrogen fixation in permaculture gardens. Likewise, El Remanso Experimental Center has allowed the application of Interdisciplinary education related to Ecological Engineering Education. The project is framed in the concepts and theories of bioeconomy, degrowth and the triangle of sustainability (Georgescu-Roegen, 1975, 1977; Latouche, 2011, 2022, 2023; Nijkamp, 2004, 2012). A qualitative methodology was considered based on the reunion with the traditional knowledge of the original peoples and the peasant communities of the area in the production and cooking of food and in the recovery of soils and ecosystems, as well as the implementation of associativity processes related to the design and execution of tourist routes. As findings, the importance of co-creation, respect for ancestral knowledge and the dialogue of knowledge are recognized, among others.

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References:

Balanzó, A., Centeno, J., Pinzón, C., Rojas-Jiménez, H. (2021) *Is bioeconomic potential shared? An assessment of policy expectations at the regional level in Colombia*, Innovation and Development, in: https://www.tandfonline.com/doi/abs/10.1080/2157930X.2021.1956713?journalCode=riad20

Camarena, J.L., Osorio Vera, F.J., Rojas-Jimenez, H., Borda Medina, E., Esteban Torregroza, J.C. and Tabares-Valencia, J.D. (2022), *Future public policy guidelines for the sustainable development of Guaviare, Colombia for the year 2035*, Foresight, Vol. ahead-of-print No. ahead-of-print. https://doi.org/10.1108/FS-03-2021-0069

Cavalcanti, M., Quispe, S., Paucar, A., Burrowes, T., Rojas-Jiménez, H (2021) *Provision of Education for Sustainability Development and Sustainability Literacy in Business Programs in three Higher Education Institutions in Brazil, Colombia and Peru*, Journal of Sustainability in Higher Education. https://www.emerald.com/insight/content/doi/10.1108/IJSHE-07-2020-0247/full/html

Georgescu-Roegen N. (1975). *Energy and Economic Myths*. Southern Economic Journal, Vol. 41, No. 3 (347-381).

Georgescu-Roegen N. (1977). *The steady and Ecological Salvation: A Thermodynamic Analysis*. BioScience Vol. 27 No.4 (266-270).

Goméz, M., Rojas-Jiménez, H. (2019) *¿Crecimiento verde y bioeconomía sin pueblos indígenas? La inconstitucionalidad del Conpes 3934,* en: García, M. (Ed) (2019). Lecturas sobre derecho del medio ambiente, Bogotá: Universidad Externado de Colombia, https://medioambiente.uexternado.edu.co/lecturas-sobre-derecho-del-medio-ambiente-tomo-xix/

Latouche, S. (2011) *¿Decrecimiento o Barbarie?,* https://www.economiasolidaria.org/recursos/biblioteca-charla-de-serge-latouche-decrecimiento-o-barbarie/

Latouche, S. (2022) *El decrecimiento o el sentido de los límites,* https://www.climaterra.org/post/el-decrecimiento-o-el-sentido-de-los-l%C3%ADmites

Latouche, S. (2023). *Introducción al decrecimiento*, Editorial Popular

Nijkamp, P. (2004). *Environmental Economics And Evaluation*. Vol. 4., Edward Elgar.

Nijkamp, P. (2012). *Interaction, evolution and chaos in space,* Springer.

Rojas-Jimenez, H. (2020). How the bioeconomy can contribute to the local economic development in Colombia?, en: Journal of Fundamentals of Renewable Energy and Applications, Vol 10. No.4, https://www.longdom.org/open-access-pdfs/how-the-bioeconomy-can-contribute-to-the-local-economic-development-in-colombia.pdf

Rojas-Jimenez H. (2021a) Local Economic Development and the Colombian Strategy for a Sustainable and Inclusive Bioeconomy. In: Orozco L.A., Ordóñez-Matamoros G., Sierra-González J.H., García-Estévez J., Bortagaray I. (eds) Science, Technology, and Higher Education. Palgrave Studies in Democracy, Innovation, and Entrepreneurship for Growth. Palgrave Macmillan, Cham. https://www.palgrave.com/gp/book/9783030808310

Rojas-Jiménez, H. (2021b) Menos calentamiento, más bioeconomía, en: Gómez, M, (2021) Ahora o nunca. Gobernanza, coproducción y bioeconomía contra el cambio climático, ISBN: 978-958-790-618-9 https://bdigital.uexternado.edu.co/entities/publication/d0e3567b-5344-4b87-bbf2-80ab22088822

Rojas-Jiménez, H. Mojica Godoy, A. (2023a) Colombia Bio como vehículo de la bioeconomía en el Plan Nacional de Desarrollo 2018-2022, en: Seguimiento y análisis de Políticas Públicas en Colombia 2022, Bogotá: Universidad Externado de Colombia, ISSN 2357-6227. https://publicaciones.uexternado.edu.co/gpd-anuario-de-seguimiento-y-analisis-de-politicas-2022.html

Rojas-Jiménez, H., Herrera-Chiquillo, F., Guzmán-Aguilera, P., Rodríguez-Muñoz, F.; Triana-Vega, A.; Pinzón-Camargo, M.; Beltrán-Vargas, D. (2023b) Governance and Articulation from the Externado de Colombia University with Its Environment: A Look from the Multifunctional and Territorialized Agri-Food Systems. Land 2023, 12, 65. https://doi.org/10.3390/land12010065

Advancing sustainability in industrial supply chains by embracing circular approaches & digital transformation

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Keywords: industrial resiliency, sustainability, circularity, digitalisation tools, industrial value chains

ABSTRACT

Sustainable growth has been assuredly connected with the integration of circularity, sustainability, innovation and resiliency into the value chains. Towards this path drives the recently updated European Circular Economy Action Plan (CEAP, 2020), a fundamental component of Europe's agenda for sustainability and resiliency, the European Green Deal (EU Green Deal, 2019). On the other hand, Europe foresees achieving both a green transition and digital transition during the Digital Decade, focusing mainly on high energy-consuming industrial facilities towards a net-zero industries concept. The green transition, as being reinforced by circularity, is called to accompany the digital transition towards climate neutrality, a target that has been underlined as a key requirement in the EU's green agenda (Digital Europe, 2022).

The industrial environments, as an intensive energy consumer, aspires to move towards green and digital transition, where the efficient management of resources, the need for prevention and the circular designing and planning, have shown the path towards alternative approaches, new technologies and services, and cutting-edge solutions. Digitalisation technologies, circular supply chains, secondary raw materials, integrated sustainability frameworks and standards, digital twins and cognitive digital twins, the newly introduced DPPs - Digital Product Passports, are some of the solutions and tools that assemble to facilitate a green and digital transition, considering the circular economy aspects, and targeting to resiliency and sustainability.

Under this scope, the Horizon Europe Plooto project valorises available sustainability and governance frameworks and models to design and develop an integrated methodological approach for "closing-the-loop" in industrial value chains, the Sustainability Balanced Scorecard Framework. This framework is demonstrated in three robust use cases, representing the food and manufacturing sectors. The ordinary supply chains of a citrus juice company in Greece, the processes of managing Waste Electrical and Electronic Equipment (WEEE) for magnets and Carbon Fiber Reinforced Polymer (CFRP) for drones, are assessed using the Sustainability Balanced Scorecard, to empower the business opportunities, to enhance traceability and lead to sustained value chains.

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References:

European Commission, March 2020, CEAP – A new Circular Economy Action Plan For a cleaner and more competitive Europe, COM/2020/98, https://eur-lex.europa.eu/legal-content/EN/TXT

European Commission, December 2019, A European Green Deal, official website of European Commission, accessed in 22.02.23, available at: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

European Commission, June 2022, A green and digital future: 7 insights from strategic foresight, accessed in 22.02.23, available at https://joint-research-centre.ec.europa.eu/jrc-news/green-and-digital-future-7-insights-strategic-foresight-2022-06-30_en

European Commission, March 2022, Towards a green, digital and resilient economy: our European Growth Model, accessed in 22.02.23, available at: https://ec.europa.eu/commission/presscorner/detail/en/IP_22_1467

European Commission, 2022, Shaping Europe's digital future, Green digital sector, accessed in 22nd of February 2023, available in: https://digital-strategy.ec.europa.eu/en/policies/green-digital

Chauhan C., Parida V., Dhir A. (2022), Linking circular economy and digitalisation technologies: A systematic literature review of past achievements and future promises, Technological Forecasting and Social Change, 177.

Carraresi L., Bröring S., How does business model redesign foster resilience in emerging circular value chains? (2021), Journal of Cleaner Production, 289, 125823, ISSN 0959-6526.

Eirinakis P., Lounis S., Plitsos S., Arampatzis G., Kalaboukas K., Kenda K., Lu J., Rozanec J., Stojanovic N. (2022), Cognitive Digital Twins for Resilience in Production: A Conceptual Framework, Information, 12, Issue 1, DOI: 10.3390/info13010033

Genovese A., Acquaye A., Figueroa A., Koh K. (2017), Sustainable supply chain management and the transition towards a circular economy: Evidence and some applications, Omega, 66, Part B, 344-357.

Tsinarakis G. Sarantinoudis N., Arampatzis G. (2022), A Discrete Process Modelling and Simulation Methodology for Industrial Systems within the Concept of Digital Twins, Applied Sciences, 12, no. 2:870.

Eco-traditional buildings in Makkah: Al-Byaddiah Palace as a case study

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Keywords: eco-architecture, traditional building, Makkah, Al-Byaddiah, Shubbak, courtyard

ABSTRACT

History has its own pearls of wisdom and lessons that can help us develop and gain new ideas. The traditional architecture of the holy capital of Islam has its essence, which reflects sustainability criteria. Makkah has a significant role due to its status and its location as the heart of the Islamic world. Makkah had a rich history and a profound religious identity even before Islam as a crossroad of the trade route even before Islam (1). However, the basic components of Makkah traditional buildings were established more than 900 years ago, according to historians and travellers. Makkah settlements consist of multi-storeyed houses, positioned in a densely built compact pattern with irregular streets; the number of storeys varies between four and six. This built heritage reflects the local identity and the fusion of mixed populations who have lived in Makkah through the ages. The architectural heritage, traditional architecture with their inhabitants, and their norms and cultural values produce this fabric. Simply because Makkah is a melting pot for a vast mixture of origins and cultures and has a unique architectural fabric that reflects this rich mixture (1). This study aims to stress the sustainability of one of the remaining palaces in Makkah which is called (Al-Byaddiah), which is believed to have existed since 1788 AD (2). It focuses mainly on the ventilation system via traditional openings (specific window type) and the courtyard. Accordingly, the descriptive methodology is used to highlight the historical traditional building and the main features of the palace. The analytical and case study methods are followed for the in-depth background of Al-Byaddiah Palace, mainly to learn lessons from the past, and to educate the current generation.

Al-Byaddiah is formerly known as Al-Hukum Palace, however, the historian reader Fawaz Aldahas claims that it is wrongly named as Al-Saggaf Palace (Fig. 1). Interestingly, the Palace housed a prominent figure in Saudi Arabia's history, King Abdul Aziz bin Saud, who lived here when he entered Makkah to unite the country in 1924 (1,3). This historical fact adds charm and national importance to the palace's history (1). Currently, the palace and the whole site belong to the Saudi Ministry for Culture. The palace is a masterpiece that reflects the techniques of the eco-architecture system. Al-Byaddiah and its surrounding mirrors how the previous generation presented the concept of such architecture in the western part of Saudi Arabia (Hijaz region). It is situated in the city of Makkah, in Al-muda'a district, around four kilometres from the holy masjid. This area is of great historical interest and stretches out for two hectares (4). The total area of the palace is 9000 square meters, and it is divided into several parts so that each part consists of two floors. The area of each floor is 4500 square meters, consisting of more than a hundred rooms (2). The palace also includes reception chambers and a massive theatre (Fig. 2) which were used to host world leaders at the Muslim World League conference (3). In fact, King Abdulaziz received the official guests of the state at the palace, and it continued during the reign of King Saud and King Faisal in his official capacity (5). Architecturally, Al-Byaddiah bares many original architectural features that reflect Makkah's real old cultural heritage. Al-Byaddiah palace has mixed and merged styles, such as Roman and Andalusian as Aldahas claims (2). The central area of the palace was distinguished by the presence of a bridge connecting all its parts. Aldahas also argues that the palace has managed to keep its strength, which is evidence of the building's capacity to endure, despite the variety of transformations as well as tremendous obstacles (2).

Saudi Arabia has some of the world's hottest climate conditions due to its location, whereas Makkah is situated in a dry valley surrounded by mountains on all sides. The topography of Makkah influenced the formation of the city's urbanization and architecture due to the slopes of the mountains (1). The residents of Makkah desired to reside in areas that provided a comfortable environment in the winter and a chilly environment in the summer (2). This smart way of thinking and applying human needs according to the environment is evident in the built environment in Makkah. Such an equation, which is a tendency among many world institutions in relation to architecture and well-being, has been naturally embedded in Al-Byaddiah. Studies claim that it is essential for our well-being to receive the recommended daily amount of sunlight (6). Gligorovski and Abbatt argue that research indicates that 90% of individuals desire to reside in a comfortable, environmentally responsible setting. Therefore, in traditional buildings, efforts have been made to develop ventilation and illumination systems that can sustainably enhance the quality of life (7). The International WELL Building Institute has missions to achieve, and one of them is: “We aspire to transform buildings and organizations in ways that advance health and well-being to help people thrive” (8). Regarding the air concept, the aim is to achieve high levels of indoor air quality across a building’s lifetime through diverse strategies (8). This study reflects the same aim being adopted in Makkah traditional buildings ages ago, for the sake of human satisfaction and fundamental needs.

Figure 1: Al- Byaddiah Palace (source: photo by Al-Hadath)

Figure 2: Al- Byaddiah Palace theatre (source: photo by Layan)

Based on the factor of air quality in the built environment, the openings and the courtyard of the palace are the main elements to emphasise. The windows in Makkah and the Hijaz region are locally called “Shubbāk”. This study stresses one specific type which is called “Shubbāk Qalāb”. “Qalāb” is a singular local term, and the plural is “Qalalīb” which means louvers. This type of window treatment is one of the most commendable techniques in Al-Byaddiah, which embodies the concept of eco-architecture. This shubbāk provides cultural privacy features for the inhabitants. The shubbāk Qalāb has demonstrated its viability as a ventilation system that creates a habitable environment (Fig. 3). It is an effective method for providing adequate illumination in buildings. The technique of this kind of shubbāk allows air to enter through the louvers (Qalalīb) within the window. The air will then circulate within the room and draw air out of the room through the orifice beneath it (Fig. 5). This hidden opening, close to the floor of the room, exists beneath some windows and works functionally to smooth air circulation within the room. An innovative environmental method of natural ventilation process via these small slant openings where high-quality outdoor air exchanges from the open corridor to the interiors. One of the features of Shubbāk Qalalīb is the louvers (Qalalīb) in the middle part which consists of two panels: one fixed and one sliding. The sliding section has two moveable and sliding panels. Each panel has a control vertical stick that allows the user to modify the opening angle, and to control and alter the quantity of air and light in the room. These parts of the shubbāk give the user the option to slide and lift, to have an entire open window (Fig. 4).

Figure 3 Shubbāk Qalalib (source: photo by Layan)

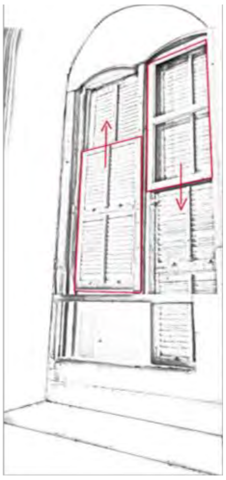

Figure 4 Shubbāk Qalalib (source: Sketch by Layan)

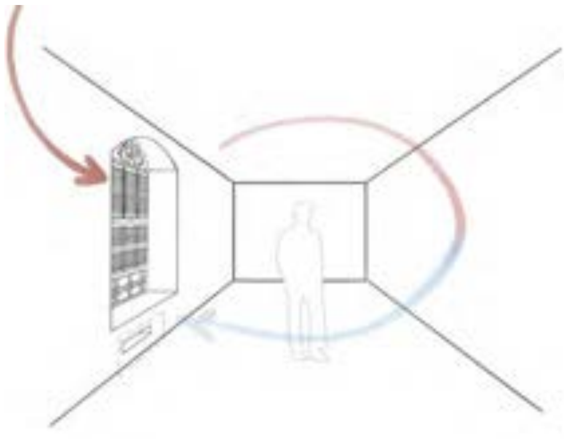

Figure 5 Airflow Shubbāk Qalalib (source: sketch by Layan)

3

Generally, courtyards have been referred to as a microclimate changer, due to their ability to mitigate high temperatures, channel breezes, and adjust the degree of humidity. These architectural features provide well-air distribution within the interior spaces in the very hot weather of Saudi Arabia, especially in summer (9). In this case, the courtyard is a major architectural element with an open space inside the building that allows access to sunlight and circulates ventilation that connects the exterior to the interior to provide a unique sense of comfort and permanent renewal as a result of changing angles of view as we move throughout the building (6). The rectangular courtyard of Al-Byaddiah utilizes a dynamic flow ventilation system in which one or two walls are at a different height than the other walls, allowing air to flow into the courtyard (Fig. 6). Environmentally, the essential function of Al-Byaddiah courtyard is reducing the temperature significantly, especially during the moderately cold night when the floor of the yard is colder. The cold air is denser than hot air and therefore moderately cold air gathers in layers inside the yard (6). This cool air flows quietly to the inner rooms which play a major role in reducing the temperature. Whereas, during the day the floor of the yard is hotter due to the sun ray's exposure. Therefore, the air near the floor of the yard heats up and rises to the top and replaces the cold air that is shaded by the walls of the yard. Thus, the movement of hot and cold air inside the yard works to preserve a largely moderate temperature throughout the day. The experience of such a mechanism is felt and observed during the site visit (3).

Al-Byaddiah courtyard provides another advantage that helps reduce the temperature, and this feature is represented in the shadows corresponding to the walls surrounding the inner courtyard. The continuous presence of shadows throughout the day greatly helps in providing and continuing cold air currents. Moreover, Al-Byaddiah courtyard works to achieve a great environmental benefit for humans, as the dust resulting from sandstorms causes' disturbance and irritation to the eyes and nose. These storms are well known for the dry and desert climate of the Arab region in general. The high walls of the Al-Byadyah Palace and courtyard prevent the arrival of dust while providing the advantage of enjoying the air breeze and sunlight (Fig. 7). Studies confirm that dust particles cannot rise more than one meter above the ground even with strong winds (6). One of the most creative ideas that were used in the Al-Byaddiah palace is using the combination of the courtyard and the shubbāk Qalalīb in sequence to have the most air flow possible in the rooms. Starting with the Al-Byaddiah courtyard and the flow that was created from it to cool the walls and the aisle to the shubbāk, which is going to do the second air circulation using the airflow coming from the Al-Byaddiah courtyard. This in turn mechanism allows the interior spaces to get cooler in the summer and warmer in winter.

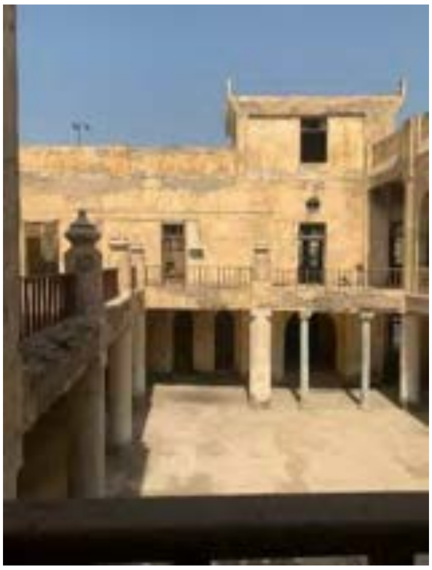

Figure 6 Al-Byaddiah Courtyard (Source: photo by Layan)

Figure 7 Al-Byaddiah Palace Air Flow Dynamic (source: sketch by Layan) [4]

The study concluded that the ventilation systems used in traditional buildings are effectively sustainable due to their role in creating a dynamic flow system that improves ventilation and lighting in buildings. The analysis of Al-Bayadiyah case study demonstrates that sustainability is a well-known concept in Makkah traditional architecture and can be implemented in several ways. The case study also showed that the concept of sustainability is not new, in contrast to the well-known old concept that is constantly being developed and updated. It was explained by many techniques used in the Saudi architectural heritage such as windows and the role of this technology in ventilation and lighting accordingly. It also refers to Al-Byaddiah Palace technique, which is based on the presence of an open space in the centre of the building connected to the interior spaces that provide interior spaces and corridors with lighting and ventilation system. This study's findings go parallel with scholars' studies in arguing that the efficient application of courtyards as a sustainable technique served the climate of the region wisely and provided healthy ventilation and enough energy to raise the level of the building performance of light and ventilation alike (9). Finally, ancient structures, such as this majestic palace, are a reminder that sustainable practices are deeply rooted in our history and have the power to lead us to a future that is more environmentally aware and focused on society. These are two elements being studied from one of the remaining traditional architectural fabrics from Makkah, and the rest are worth more analysis. Truly, there is more to learn from our traditional history and the previous generation.

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References:

(1) Al-murahhem, Faredah M, 2021. Makkah: City of Self-Identity and Inspiration. *Art, Design & Communication in Higher Education*. 20, 7 – 28.

(2) Aldahas, Fawaz (Reader in history – Umm al-Qura University). Personal interview with Layan Rayes. September 29, 2022.

(3) Rayes, Layan, October 30, 2021: Site visit and data collection. The two visits were accompanied by members from with Ministry of Culture and a construction engineer.

(4) Al-murahhem, Faredah M, 2014. A New Interpretation of Local Built Heritage. *Fine Arts Magazine*. Alexandria University. Egypt, 67 – 93.

(5) Al-Hadath, (26 July 2019). Photos of the Royal Palace in Makkah, Impressive architectural details. Al-Hadath report. (http://hdth.tv/89u7q, accessed April 2022.

(6) Mohammed, Heba Abdullah, and Others, 2022. Alfinaa Wa Ahamiyatuhu Alwazifia Fi Alamayir Aldiynia Walmadania Khilal Al'asr Alisalmi. *International Journal of Tourism and Hospitality Studies*. 1, Vol 2,17 – 35. https://ijthsx.journals.ekb.eg/article_225503_5264c6bdb6500d2e843c5317350eb1f3.pdf

(7) Gligorovski, Sasho and Abbatt, Jonathan, 2018. An indoor chemical cocktail, *Science* 359, 632 – 633. https://www.science.org/doi/10.1126/science.aar6837

(8) The International WELL Building Institute: https://v2.wellcertified.com/en/wellv2/overview, and https://v2.wellcertified.com/en/wellv2/air. Accessed March 2023.

(9) Elantary, Asmaa R. and Eldeeb, Ayah Salem, 2023. Courtyard Existence between the Past and the Present, Case Study: Central Region, Saudi Arabia. *Civil Engineering and Architecture*, 11(2), 675 – 695. https://www.researchgate.net/publication/368471714

Sustainability of Process Industries through Digital and Circular Water Use Innovations – Experience from AquaSPICE project

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Keywords: water treatment, process industry, circular economy, cyber-physical systems, digital twins

ABSTRACT

For the vast majority of industrial products water is used during some stages of the production process. It is estimated that 20% of all fresh water consumption globally is used by industry and this share is increased to 50% in industrialized countries. The industrial sector is also a major water polluter, as only up to 60% of industrial wastewater receives treatment before being disposed of into the environment. Eco-efficient and sustainable industrial water management is a priority within the integrated water resources management strategy and is regarded as one of the most important focus areas for environmental protection in many countries. Innovation in water treatment can bring close loops to at almost 100% for important industrial water users and enable new multi-billion-euro markets in saved or recovered and reused resources .

AquaSPICE is an ongoing H20-20 project, aiming at materializing circular water use in the European Process Industries, fostering awareness in resource-efficiency and delivering compact solutions for industrial applications. That challenging aim necessitates (i) multiple state-of-the-art (SotA) water treatment and re-use technologies, (ii) diverse closer-loop practices regarding water, energy and substances, (iii) a cyber-physical-system controller in the form of a system for real-time monitoring, assessment and optimization of water (re-) use at different interconnected levels and (iv) an effective methodological, regulatory and business framework. The consortium follows a systemic approach in water management where optimal efficiency can be achieved through an adaptation of appropriate technologies and practices in different levels, from a single industrial process (unit operation), to an entire factory, to other collaborating industries (industrial symbiosis) or other sectors (e.g. domestic and/or agriculture).

The key innovation of the AquaSPICE project is the development of WaterCPS, a Cyber-Physical System specialized to enhancing water efficiency in the Process Industry. Water efficiency enhancement is approached from three directions: (a) diagnostic (monitoring water efficiency, diagnosing problems, estimating improvement margins); (b) production chain enhancement (application of SotA water recovery technologies & practices); and (c) optimization (of water use/recovery/reuse processes). WaterCPS consists of a physical part and a cyber (digital) part. The physical part comprises of the industry's existing production line(s) and value chain(s), plus the new SotA water efficiency technologies & practices selected, configured and deployed. The cyber part consists of the Digital Twin (incl. its knowledge core, models and cognitive services & tools), the Real Time Monitoring system (RTM) and the WaterCPS digital Platform (incl. data/control connections & management, interfaces & user applications, access control components). The RTM plays the role of intermediary between the physical system and its digital twin, with its sensors incorporated as part of the physical system and its data communication & management components incorporated as part of the cyber system. The expectation from AquaSPICE is that the cyber part of WaterCPS and its integration with the water efficiency technologies & practices, will create significant added value for them and have a measurable impact on water efficiency by supporting the above mentioned three directions to water efficiency enhancement.

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Session A7: Sludge management

A pilot study of domestic sewage sludge dewatering using Sludge Treatment Reed Beds in Oman

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Keywords: constructed wetlands; sludge drying reed beds; sludge treatment wetlands, sludge management; sewage sludge; nature-based solutions

ABSTRACT

Sultanate of Oman produces a high volume of wastewater on a daily basis. Since conventional / mechanical wastewater treatment methods are mostly used in the country, a respectively high volume of sludge by-product is also generated daily. Sludge is defined as a mixture of water, organic matter and inorganic matter resulting from the biological treatment of wastewater. Oman manages the generation of sludge by discharging about 84% of it in the landfills, especially the Sewage Treatment Plants (STPs) located outside the capital city of the country (Muscat Governorate), while about 16% of produced sludge is collected by Oman Water and Wastewater Services company and is further processed through composting to produce a fertilizer ('Kala' brand name). This compost production covers a small amount of the sludge volume, while the associated high costs make it prohibiting to upscale this practice to all STPs across the country. In addition, many small STPs in the country simply dump the generated sludge to the environment after simply sand drying process.

For these reasons, revolutionary and cost-effective means and ways are needed to manage the sludge for environmentally friendly sound disposal and reuse. One of the promising and state-of-the-art sustainable technologies is the constructed wetland technology for dewatering and stabilization of sludge. The Sludge Treatment Wetland (STW) system depends on the type of substrate, type of plants and microbial communities that play an important role in the treatment and dewatering of the sludge. In addition, it contributes to the decentralized management of sludge, a parameter that is crucial for small and medium STPs.

This study focuses on the construction of STWs, i.e., vertical flow constructed wetland designed for sludge dewatering, using local common reed plants (*Phragmites Australis*) to treat activated sludge from Alseeb STP. A pilot scale experiment was conducted in an agricultural experiment station. This study is the first one in Oman and across the Arabic peninsula that tests the STW technology. The study consisted of 18 mesocosms tanks. Each tank has dimensions of 89 cm in height and 0.5 m² surface area. The freeboard in each tank was 54 cm above the top gravel layer. The units are filled with substrate media from top to bottom: 15 cm fine gravel (2-6 mm), 15 cm medium gravel (15-25 mm) 5 cm and drainage layer of cobbles (40-60mm). Two plastic tubes extending vertically with an open top are embedded in the bottom of each unit. The various units have different construction and operation parameters such as planted and unplanted beds (i.e., presence and absence of plants) and three different sludge loading rates (SLR; 75, 100, 125 kg/m²/year).

The results showed the dewatering efficiency reached 97% for the planted STWs compared to 91% for the unplanted beds. The total solids content in the dewatered sludge for the three SLRs (75, 100 and 125 m²/kg/year) were between 23 -56%, 16-57% and 11-42%, respectively. These first results demonstrate that a high total solid content in the dewatered sludge can be achieved even at a relatively high SLR of 100 m²/kg/year after 2 years of operation. This means that the dry content can be further increased in the final resting phase that is going to be applied before the emptying of the biosolids from the units.

References:

Al-Wahaibi, B., Jafary, T., Al-Mamun, A., Baawain, M.S., Aghbashio, M., Tabatabaei, M., Stefanakis, A.I., 2021. Operational modifications of a full-scale experimental vertical flow constructed wetland with effluent recirculation to optimize total nitrogen removal. Journal of Cleaner Production 296, 126558, https://doi.org/10.1016/j.jclepro.2021.

Nielsen, S., Stefanakis, A.I., 2020. Sustainable Dewatering of Industrial Sludges in Sludge Treatment Reed Beds: Experiences from Pilot and Full-Scale Studies under Different Climates. Applied Sciences 10 (21), https://doi.org/10.3390/app10217446.

Stefanakis, A.I., Al-Rashdi T.T., Ahmed, M., 2022. Research and Case Studies of Sludge Treatment Wetlands in Hot and Arid Climates: Experiences and Opportunities for Sustainable Sludge Management. In: A. Stefanakis, (ed.), Constructed Wetlands for¬ Wastewater Treatment in Hot and Arid Climates. Wetlands: Ecology, Conservation and Management Vol 7. Springer Nature, Cham, Switzerland, pp. 257-274, https://doi.org/10.1007/978-3-031-03600-2_15.

Stefanakis, A.I. and Tsihrintzis, V.A., 2012. Effect of various design and operation parameters on performance of pilot-scale Sludge Drying Reed Beds. Ecological Engineering 38, 65-78.

Stefanakis, A.I., 2020. Constructed Wetlands for Sustainable Wastewater Treatment in Hot and Arid Climates: Opportunities, Challenges and Case Studies in the Middle East. Water 12 (6), 1665, https://doi.org/10.3390/w12061665.

Stefanakis, A.I., 2018. Constructed Wetlands for industrial wastewater treatment, first ed. John Wiley & Sons Ltd, Chichester, UK.

Sludge Treatment Constructed Wetland: a solution for treating sewage sludge for agricultural reuse

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ABSTRACT

The global population has led to an increase in solid waste production from industrial, residential, and public sources. Every year, 4 billion tons of waste are generated, and municipal waste accounts for 1.6 to 2 billion tons. Wastewater treatment plants (WWTP) produce sludge, which is a type of solid waste containing organic and inorganic materials. The amount of sludge produced depends on the parameters of the effluent and the type of treatment used, typically ranging from 60-80 g TS/person/day when using standard activated sludge processes (Andreoli, et al., 2007). Stabilized sludge (also known as biosolid) typically has between 50-70% organic matter, 3-4% nitrogen, 1-3% phosphorous, and trace levels of heavy metals like Cr, Zn, Pb, Ni, and Cd. Sludge management strategies should focus on both pollutant removal and biosolids reuse to reduce potential health and environmental risks and make the material harmless and more reusable.

Developed and developing countries are looking for ways to manage sludge produced in WWTP. Solutions such as thermal processing, composting, disposal, and agricultural use are being explored. Agricultural use is gaining more attention since sludges contain components that can act as soil conditioners or fertilizers, providing an alternative to commercial fertilizers and adding value to wastewater treatment by-products. However, the sludge must be treated before to be reused. For these reasons, sludge treatment constructed wetlands (STCWs) are gaining more attention as a solution due to their ability to treat sludge in a sustainable, low-energy, and low-maintenance manner and obtain a by-product suitable to be reused in agriculture. The aim of this study was to evaluate the capacity of CWs to generate stabilized biosolids after different periods of rest (without feeding) and to test their compliance with the requirements established by European legislation for agricultural reuse (European Commission 2000). Moreover, agronomic essays were carried out in agronomic crops (i.e. wheat) to test biosolids properties as organic fertilizer.

In this context, the present study has two main objectives: to characterize the sludge treated in STCW, and to evaluate the quality of the biosolids in an agronomic essay. The facilities studied in this work are located in the WWTP Sentfores-La Guixa (1000 PE) (site A) and the WWTP Santa Eulàlia de Riuprimer, (2000 PE) (site B), both located in Vic (Barcelona, Spain). Three sampling campaigns have been carried out during 6 months starting one week after the CWs received the last feeding (June 2022). Samplings were carried out in June 2022, September 2022, and December 2022. In order to obtain a composite sample of the sludge, in each facility one representative bed was selected and divided into 4 sections, 1 sample was collected in each section and then carefully mixed. Samples were analysed in triplicate using standard techniques in accordance with the Standard Methods (APHAAWWA-WPCF, 2001). The following parameters were analysed: pH, Electrical Conductivity (EC), Total and Volatile Solids (TS and VS), Chemical Oxygen Demand

(COD), Total Kjehldahl Nitrogen (TKN), nutrients, heavy metals, and faecal bacteria indicators (*Salmonella spp*, *E. coli*, faecal coliform and nematode eggs).

Furthermore, the agronomic essay was carried out at the Tona WWTP located in the Osona region of Barcelona province. Three fertilizer treatment were considered: biosolids from CW applied directly to the soil (T1), biosolids from CW after crushing (T2) and commercial inorganic fertilizer (T3). The doses of sludge and commercial fertilizer were calculated with respect to the nutritional needs of the crop and the concentrations of total nitrogen in biosolids and fertilizer. For biosolids, 2 $t{\cdot}ha^{-1}$ of T1 and 3 $t{\cdot}ha^{-1}$ of T1 and T2 were applied in the agronomic assay. Each treatment was carried out in triplicate in smallholdings of 3x8 m^2 (figure 1). All fertilizers were homogeneously mixed with the soil at the beginning of the experiment, then 200 Kg ha^{-1} of wheat seeds (KWS ultim) were planted in each smallholding. During the testing period (6 months), samples of the plants and soil were taken to measure the different parameters stablished by the directive AAA/1072/2013 (MAGRAMA 2013).

The physicochemical characterization of the sludges from STCW during three sampling campaigns is shown in table 1. The pH and EC values were similar to those previously reported for biosolids quality (Stehouwer et al. 2022). The sludge after 6 months without feeding has reduced its moisture from 33%TS to 50%TS in the system of La Guixa and 35%TS to 50%TS in St. Eulàlia. The organic content of the biosolids in all basins studied was quite uniform (40-49%SV) and in accordance with previous studies (Uggetti et al., 2009). Biosolids contain a large amount of nutrients (4.6% TKN/TS for La Guixa and 5.7%TKN/TS for St. Eulàlia).

Table 3. Physicochemical characterization of sludge in rest for 6 months in sludge treatment reed beds.

Parameters	Unity	Campaign I June 2022		Campaign II September 2022		Campaign III December 2022	
		Site A	Site B	Site A	Site B	Site A	Site B
pH		5.6	6.4	5.2	5.7	5.0	5.4
EC	dS/m	0.3	0.5	0.3	0.5	2.17	2.75
TS	%	33	35	53	47	50	50
VS	% TS	43	41	40	41	38	49
COD	g/kg TS	480	519	553	541	533	558
TKN	%TS	-	7.2	4.6	5.9	-	5.7
P_2O_5	%TS	9	7	9	7	8.74	6.91
K_2O	%TS	1	1	1	1	0.75	0.85

Finally, the concentration of the heavy metals was evaluated to verify their potential in agricultural application (table 2). In all basins there was a small accumulation of metals, such as Cu, As, and Mn in the three basins; and Zn and Cr in the St. Eulàlia basin. However, despite the slight accumulation of these metals, concentrations do not exceed the thresholds established in the European Directive (European Commission 2000). Lastly, indicators of faecal contamination were analysed, in particular to evaluate the quality of the final product for its application in agriculture. According to the results, *Salmonella spp* was not detected in any samples. *E. coli* was present in the three sampling campaigns and their presence increased along the sampling period. Nematode eggs were present just in the first campaign, but in the third campaign it was not detected (table 3).

Crop trials are currently taking place, and it is expected that the sludge will favour the wheat crop performance due to its high content of nitrogen and other nutrients, thus it could be considered as an organic fertilizer. It is expected that, the addition of biosolid (organic fertilizer) will increase the plant weight compared to the inorganic fertilizer as reported by Bouzerzour et al. (2002) in their pot studies. Indeed, they detected an increase in leaf diameter, leaf area index, accumulated dry matter on the soil, tiller number, and plant height of crops such as barley and oats. Latare et al.(2014) reported a wheat yield of 39.21 $g \cdot pot^{-1}$ using a sludge concentration of 40 $t \cdot ha^{-1}$. According to these studies, good results are expected with biosolids from CW.

Table 4. Heavy metals (mg/kg TS) in biosolids from the 3 STW of the resting period.

		Cd	Cu	Hg	Ni	Pb	Zn	As	Cr	Cr VI	Mn
Campaign I June 2022	La Guixa	0,6	406	0,4	27,3	72,9	597	14,6	60,2	0,5	310
	St. Eulàlia	0,8	354	0,4	36,3	77,5	893	11,5	50,9	0,5	310
Campaign II September 2022	La Guixa	0,5	339	0,4	29,3	66,9	630	13,5	52,6	10	325
	St. Eulàlia	0,6	304	0,4	36,9	93	808	12,6	46,6	10	260
Campaign III December 2022	La Guixa	< 0,5	356,5	0,4	26,85	64,1	627,5	13,9	49,9	10	360
	St. Eulàlia	0,6	345,5	0,4	36,1	79	869	12,5	50,2	0,5	345
3rd Draft EU Working Document		10	1000	10	300	750	2500	-	800	-	-

Table 5. *Salmonella spp, E. coli,* faecal coliform and nematode eggs in biosolids from 3 STW of the resting period.

Parameters	Unity	Campaign I June 2022		Campaign II September 2022		Campaign III December 2022	
		La Guixa	St. Eulàlia	La Guixa	St. Eulàlia	La Guixa	St. Eulàlia
Salmonella spp	Absence/Presence in 25 g	Absence	Absence	Absence	Absence	Absence	Absence
E. coli	UFC/g	650	11,850	500	1,300	<100	37,050
Faecal coliform	UFC/g	34,050	665,000	49,300	48,500	140,000	427,350
Nematode eggs	in L	<1	<1	Absence	Absence	Absence	Absence

Figure 12. Schematic image of the experimental design

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References:

Andreoli, C., M. Von Sperling, and F. Fernandes. 2007. *Sludge Treatment and Disposal*. IWA publishing.

Bouzerzour, H., L. Tamrabet, and M. Kribba. 2002. "Response of Barley and Oat to the Wastewater Irrigation and to the Sludge Treatment. In: The Proc. Int. Seminar: Biol. Environ. University Mentouri, Consantine, Algeria, p. 71." *Curso Teórico Práctico De Inseminaciónartificial En Bovinos* 1.

European Commission. 2000. "Working Documento on Sludge 3rd Draft." 80(April):1–19.

Latare, A. M., Omkar Kumar, S. K. Singh, and Archana Gupta. 2014. "Direct and Residual Effect of Sewage Sludge on Yield, Heavy Metals Content and Soil Fertility under Rice-Wheat System." *Ecological Engineering* 69:17–24. doi: 10.1016/j.ecoleng.2014.03.066.

MAGRAMA. 2013. "Orden AAA/1072/2013, de 7 de Junio, Sobre Utilización de Lodos de Depuración En El Sector Agrario." *Boletín Oficial Del Estado* 44966–73.

Stehouwer, Richard, Leslie Cooperband, Robert Rynk, Johannes Biala, Jean Bonhotal, Susan Antler, Tera Lewandowski, and Hilary Nichols. 2022. "Chapter 15 - Compost Characteristics and Quality." Pp. 737–75 in *The Composting Handbook*, edited by R. Rynk. Academic Press.

Uggetti, Enrica, Esther Llorens, Anna Pedescoll, Ivet Ferrer, Roger Castellnou, and Joan García. 2009. "Sludge Dewatering and Stabilization in Drying Reed Beds: Characterization of Three Full-Scale Systems in Catalonia, Spain." *Bioresource Technology* 100(17):3882–90. doi: 10.1016/j.biortech.2009.03.047.

Vázquez, M. A., R. Sen, and M. Soto. 2015. "Physico-Chemical and Biological Characteristics of Compost from Decentralised Composting Programmes." *Bioresource Technology* 198:520–32. doi: 10.1016/J.BIORTECH.2015.09.034.

DIALKOP project: Design and operation optimization of Sludge Treatment Reed Beds in Greece

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Keywords: constructed wetlands, sludge treatment, circular economy

ABSTRACT

Introduction

Wastewater treatment processes produce a by-product material known as sewage sludge, characterized by the point it is produced as primary, biological or secondary sludge [Nielsen & Stefanakis, 2020]. Over 50% of produced sewage sludge in Greece, ends up in landfills. Most of the small and medium-sized Wastewater Treatment Plants (WWTP) are industrial looking facilities, placed away from residential areas [Stefanakis et al., 2014], follow a linear management strategy based in mechanical and chemical methods for thickening and dewatering and also carry out daily transportation and disposal of the dried sludge in landfills. This strategy seems to be economically unprofitable while the total sludge management costs represent up to 40-60% of the operating costs of a WWTP. Linear model lead in environmental problems such as risk of surface and groundwater pollution, insufficient sludge drying and stabilization, high environmental footprint etc. DIALKOP project come to offer a circular sludge management strategy utilizing a valuable by-product with the smallest possible environmental impact. Constructed wetlands are a technology that provides huge benefits in sewage sludge management and can overcome the disadvantages of the conventional methods while it is a reliable, effective and feasible solution in the field of wastewater treatment [Stefanakis & Tsihrintzis, 2012].

Materials and Methods

Sixteen pilot-scale units of constructed wetlands were constructed in Chania WWTP area for sewage sludge treatment. Units are filled with cobbles (40-100mm) on the base, two layers of river gravel (2-8mm & 8-20mm) on the middle and with sand (0-0.5mm) on the top of two units. Two different sludge loading rates (SLR) of 60 & 80 kg/TS/y are tested as well as the contribution of greenhouse, earthworms, unit insulation and plantation. Most of the units are planted with *Phragmites australis* while there are two units with *Arundo donax* (giant reed). Unit's construction took place in March 2023 and after two and a half months of primary municipal wastewater loadings (plants adaptation period) the first sludge loading started (mid-June 2023). So far 1:1, 2:2, 3:3, 4:4, 5:5, 7:7 & 10:10 load cycles (loading period : resting period) have been implemented. Units are operating 3 months so far and having great performance both in growth and sludge dewatering.

Results and Discussion

Sewage sludge that is treated in DIALKOP project comes from secondary sedimentation tank of WWTP of Chania (that treats wastewaters of 170,000 equivalent residents) and characterized by TS=1.2% and VS=78.7(%TS).

Table 1. Total solids and Volatile solids in raw sludge

	TS(%)	VS (%TS)
average	**1,3**	**78,7**
sd	0,40	5,33
min	0,11	59,25

max	1,91	94,30

Table 2. Synthesis of raw sludge

Parameters	Values	units
MLSS	10,84	g/kg
COD	6833,37	mg/kg
TN	377,95	mg/kg
NH4-N	9,02	mg/kg
NO3-N	1,84	mg/kg
TP	93,26	mg/kg
PO4-P	10,01	mg/kg
pH	6,82	
EC	914,00	EC (μS/cm)
Bulk density	0,99	kg/L

Although the primary stage of the units, plantation have already grown and the stems height have reached an average value of 2.10m and 2.07m in SLR 60 and SLR 80 respectively. Furthermore, the highest stems appear in units with the sand layer on the top and reach up 4.25m in SLR60 and 3.75m in SLR80. As for the leachates that produced after the sludge loadings, pollutants removal seems to be quite effective despite the short period of operation of the project.

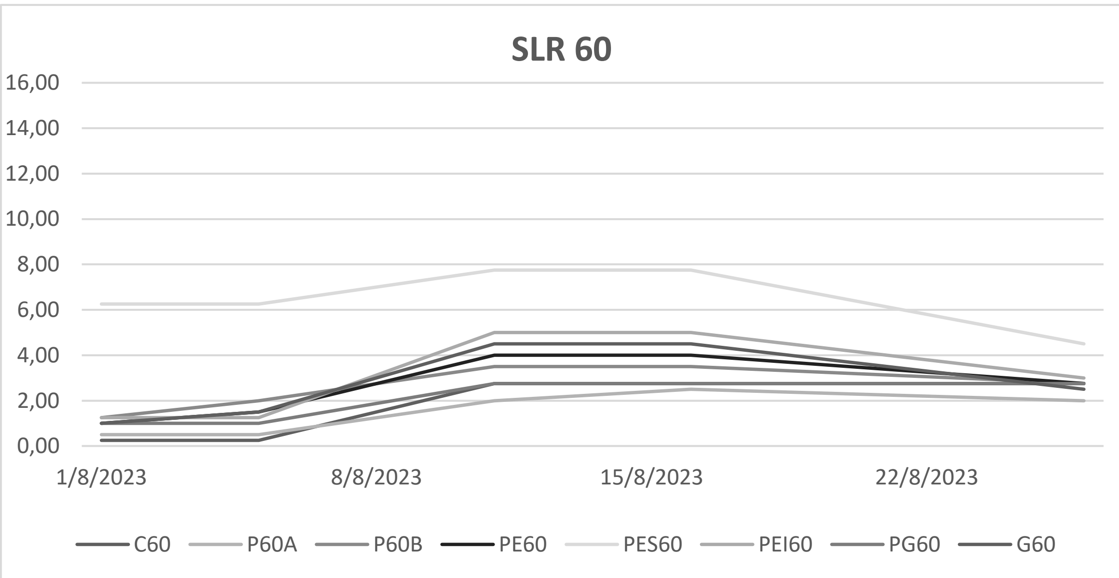

Fig 1. Accumulated sludge layer in units with SLR 60

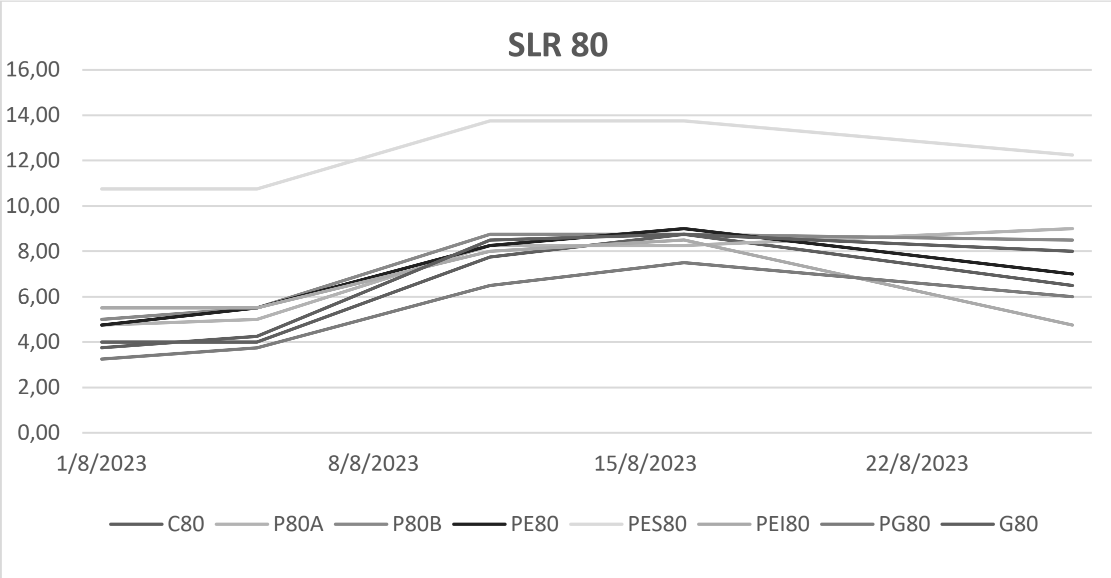

Fig 2. Accumulated sludge layer in units with SLR 80

Furthermore, accumulated sludge layer on the top of the units varies from 2-5cm and 4-14.5cm in SLR60 and SLR80 units respectively during the last measurement. In Graph 1. and Graph 2., the accumulated sludge has a thicker layer in SLR 80 compared to SLR 60 units while, units with plantation maintain a thinner layer than the unplanted units due to the high needs of evapotranspiration that causes better dewatering in accumulated sludge. Moreover, in both Graph 1. and Graph 2. can be seen that in the last measurements the layers are thinner compared with the values of the previous period. This decrease in the sludge volume is a result of the greater resting period (loading cycle 10:10). The duration of the resting period affects the dewatering efficiency. Finally, total solids (TS) content in the dried sludge has an average value of 43.1% and 20.3% and VS (%TS) content of 74.0% and 80.6% in SLR60 and SLR80 respectively.

Conclusions

Reeds growth have a great performance causing increased evapotranspiration needs which subsequently causes better dewatering of the accumulated sludge. Thickness of the dried sludge layer changes according to the duration of the resting period, the SLR and the presence of plantation. So far, the results are very promising. Soon, earthworms will be added in some units in order to see their contribution in accumulated sludge stabilization and dewatering while accumulated sludge humidity and temperature will be measured. Furthermore, greenhouse gases of the units is going to be measured in different stages of plantation growth to investigate their emissions.

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References:

Nielsen, S., & Stefanakis, A. I. (2020). Sustainable dewatering of industrial sludges in sludge treatment reed beds: Experiences from pilot and full-scale studies under different climates. *Applied Sciences*, *10*(21), 7446.

Stefanakis, A. I., & Tsihrintzis, V. A. (2012). Effects of loading, resting period, temperature, porous media, vegetation and aeration on performance of pilot-scale vertical flow constructed wetlands. *Chemical engineering journal*, *181*, 416-430.

Stefanakis, A., Akratos, C. S., & Tsihrintzis, V. A. (2014). *Vertical flow constructed wetlands: eco-engineering systems for wastewater and sludge treatment*. Newnes.

Fate of pit latrine sludge buried in entrenchments

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Keywords: Ventilated Improved Pit Latrine, deep-row entrenchment, exhumed sludge, organic content

ABSTRACT

The broader study considers the effect of sludge entrenchment on the growth characteristics of trees, soil characteristics, and changes in the characteristics of sludge buried in trenches and on the surrounding groundwater. The primary aim of this study was to investigate changes in the characteristics of VIP latrine sludge buried in trenches to determine the effect of entrenchment on the sludge and also to determine the effect of VIP sludge entrenchment on the surrounding groundwater.

In this study, it was proposed that the burial of VIP latrine sludge in association with agroforestry has the potential to turn the sludge from a problematic waste to a beneficial resource. This was because it was expected that the residual nutrients present in the sludge (especially nitrogen, phosphorus, and potassium) may be a source of fertilizing nutrients which would be released slowly and become available at the same slow rates as the sludge is degraded. According to Jönsson et al. (2004), the burial of sludge increases the organic content of the soil which enhances the moisture retention characteristics, ion-buffering capacity, and increasing generally the fertility of the soil. It has been documented that in plantations the trees planted draw the available water within the surroundings into the plantation area to supply the water requirements of the trees (Dons, 1987, Duncan, 1993), therefore planting trees near the buried sludge would have the added advantage that the presence of the trees will result in a net movement of water into the burial site to supply the water requirements of the trees. Thus planting trees next to the buried sludge would result in a lower risk of contamination of ground and surface water in the vicinity by nutrient and pathogen release from the buried sludge.

In addition, it was proposed that entrenchment of VIP latrine sludge in the soil might result in a greater degree of stabilization than can be achieved in the pit latrine. The logic behind this proposition was that field studies of pit latrines indicated that stabilization of sludge in pit latrines that are no longer in use apparently occurs from the soil/sludge interface inwards (Morgan, 2004). It was hypothesised that this observation is due to the action of soil fungi. The major processes involved in organic matter cycling in the aquatic environment are dominated by bacteria and eukaryotes (in particular algae) with bacteria found to be the dominant decomposers of organic matter in water and sediments (De Boer et al 2005; Del Giorgio and Cole 1998). However, in soils, soil fungi contribute significantly to the biodegradation of organic material. Various studies have demonstrated that the presence of organic matter in soils or organic fertilization of soil has a positive influence on the soil fungi population (Abbott and Murphy, 2003). This is because the soil contains air-filled voids which are essentially different from sediments; bacterial motility in soils is restricted due to the inability of the unicellular body form of bacteria to bridge these air-filled voids (De Boer et al, 2005). The hyphal/mycelial growth form of soil fungi makes it possible for soil fungi to bridge these air-filled voids and as such motility of fungi in soils is less restricted (Griffin, 1985; de Boer et al 2005). Also, fungi hyphae have a greater ability than bacteria to translocate nutrients within the soil (Jennings, 1987; de Boer et al 2005). The hyphal growth form has also been developed by certain soil bacterial (Actinomycetes) however heterotrophic processes and the degradation of recalcitrant organic compounds taking place in the soil is dominated by fungi (de Boer et al, 2005; Griffin, 1985). According to De Boer et al (2005), two important processes, the formation of mycorrhiza and the decomposition of lignocelluloses within the terrestrial ecosystem are dominated by fungi, and as such the functioning of the terrestrial ecosystem relies significantly on fungi. Soil fungi grow best in moist but well-aerated soil conditions with pH near neutral (Abbott, 2003); conditions within the pit, especially while in use (mostly anaerobic, significant moisture, no air-filled voids, and possibly the presence of biocidal chemicals) are

mostly not conducive to fungi proliferation. Thus cellulosic cell components that can only be broken down by certain species of fungi cannot be degraded in a pit latrine but might be biodegradable in the presence of soil fungi.

When a pit latrine is full, the sludge consists of the oldest and most fully stabilized material at the bottom of the pit and the newest, least stabilized material at the top of the pit (Bakare et al, 2012). Thus the mixed pit contents have a mixture of well-degraded and poorly degraded material. When this material is disposed of into entrenchments, it will be mixed to a certain extent during the processes of being dug out of the pit and reburied in the entrenchment, and thereafter undergo similar bio-degradative processes as occur in pit latrines, as well as some different, possibly aerobic and possibly fungally mediated processes in the entrenchment. This study investigated the changes in sludge characteristics with a length of entrenchment and explores the hypothesis that a greater extent of biodegradation can occur in an entrenchment than can be achieved in a pit latrine.

This study, analysed samples of sludge originating from pit latrines that were buried in the entrenchment site at the Umlazi E ponds entrenchment site. Sludge exhumed from pit latrines as part of the eThekwini Water and Sanitation Services (EWS) pit emptying programme was delivered to the disposal site in bins and buried in dug trenches 200 m long, 600 mm wide, and 1.2 to 1.5 m deep, with rows spaced 3 m between centres. The trenches were filled with VIP latrine sludge to within 300 mm of the surface and then backfilled with the overburden heaped. Trees were planted in rows parallel to the trenches.

On arrival at the site, sludge was sampled directly from the bins before burial to indicate the starting composition of the sludge. During the emptying of sludge content from VIP latrines, it is expected that there would be substantial mixing of pit contents, both from different locations in the pit and different pits, and thus the material that arrives at the entrenchment site is expected to exhibit characteristics that are similar to the global averages for pit sludge, and with a lower variance than at source because of this mixing. Thirty samples were collected over six weeks to assess the variability in the VIP latrine sludge that arrives at the entrenchment site.

Sampling and analysis of entrenched sludge were performed over 29 months after the entrenchment of the VIP latrine sludge. Sludge samples from the trenches were exhumed using a soil auger. The purpose of this part of the study was therefore to identify whether there was a significant change in average sludge characteristics of exhumed sludge from the trenches with time and also if a greater degree of stabilization of the sludge occurs in the trenches than can be achieved in the bottom layer of a pit latrine.

The techniques used for the characterization of samples obtained from the two components involved several biological/physical/chemical analyses which include moisture content, solids (total and volatile solids), chemical oxygen demand (COD), aerobic biodegradability, Total Kjeldahl Nitrogen (TKN) and Free and Saline Ammonia (FSA). Standard Methods (APHA, 1998) were used to analyse the collected sludge samples where applicable and where no appropriate method was published, adaptations of existing methods were used or entirely new methods were developed.

For all of the analytes investigated, the lowest values reported in this study are lower than the equivalent concentrations measured in samples taken from the bottom of a pit latrine. This means that either (i) a greater degree of stabilisation occurs in pit sludge that is buried in an entrenchment for 3 or fewer years than occurs in the pit in 14 years of operation; or (ii), the amount of sand that is entrapped in samples taken from entrenchments dilutes the measured concentration of solids. The reduction in biodegradability relative to that measured in the bottom of a pit latrine could not be accounted for by dilution with sand, since the addition of sand would dilute both total and biodegradable COD. However, the variance in the method for measurement of biodegradability in pit latrine samples is inherently large, and the measured value (16%) is not much larger than the corresponding value of entrenched sludge after 12 months (15%). Differences for COD, volatile solids fraction, and moisture content are significantly lower than the equivalent bottom-of-pit samples but these may be influenced by mixing with sand. Therefore, these results indicate that it is possible that the action of soil fungi can break down pit latrine content further than is achievable in a pit latrine, but the data is not sufficiently precise to prove the hypothesis.

Nitrogen is an essential nutrient for plant growth; the potential value of entrenching sludge with agroforestry is that nitrogen and possibly phosphorus present in the sludge may be a slow-release fertiliser for plant growth. If significant further biodegradation of sludge occurs in the entrenchment, it is conceivable that nitrogen and phosphorus will be released into the soil and available for plant uptake. Nitrogen content in the sludge before burial and after significant periods of entrenchment were measured. Nitrogen was measured as Total Kjeldahl nitrogen (TKN) and as Free and saline ammonia (FSA – NH_3/NH_4^+) according to Standard Methods (APHA, 1998).

It was found that an order of magnitude difference existed between the amount of TKN in the sludge before entrenchment and after 29 months. This amount of nitrogen may have been released into the soil and become available for nitrogen uptake in plants. There is no similar decrease in FSA concentration. This is because FSA is water-soluble and therefore will drain out of the pit with any moisture flow. Thus FSA may be regarded as an intermediate that is controlled by the rate of biodegradation of organically bound nitrogen (reporting as TKN) and the rate at which it is drained away. Therefore, FSA concentrations may fluctuate with time and location.

The amount of TKN released by the sludge is calculated from the difference in TKN on a dry basis between the two measurements, i.e. 17.2 mgN/gdry samples are lost over a period of 29 months. This corresponds to approximately 4.3 kg N/ton wet sludge. Since only one measurement interval is available, the rate of release cannot be accurately calculated but must be equal to or greater than 4.3 kg N/ton wet sludge per 29 months or approximately 1.8 kg N/ton wet sludge/year. Given that most degradation seems to occur in the first 12 months, the rate may be as high as 4 kg N/ton wet sludge/year. These findings are consistent with the findings of Taylor (2012) that tree growth associated with buried sludge showed dramatically improved growth characteristics compared to negative control, suggesting that the nitrogen and other nutrients released from the entrenched sludge may be biologically available as a fertiliser.

The findings indicate that biodegradation and dewatering occur in pit latrine sludge after it has been buried in trenches, although it is not clear how much of the change noted was a function of dilution by sand. Generally, data show high variance, but the decreasing trends are clear. It appears that an initial rapid degradation and moisture loss occurs: this is probably a result of the most recently deposited and therefore unstabilised pit latrine contents degrading. Thereafter, a slow decrease in volatile solids, COD, and moisture is observed, until final values are reached that appear to be lower than the lowest values obtained in pit latrine samples. This decrease below the concentrations measured in the samples taken from the bottom of full pit latrines, where the sludge is apparently fully stabilised, could be explained by the action of fungi that result in cellulase activity that reduces the remaining potentially degradable material.

Given the extremely large variances in determinations of concentration in this type of heterogeneous material, it will be difficult to obtain further insight into these mechanisms using additional physicochemical measurements. However, the role of fungi in the stabilisation of sludge in entrenchments could be further investigated through biochemical and microscopic techniques.

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References:

Abbott L. and Murphy D (2007). Soil biological fertility: A key to sustainable land use in agriculture Springer (Netherlands)

APHA (1998). Standard methods for the examination of water and wastewater. 20th Edition

Bakare B.F. (2014) Scientific and management support for ventilated improved pit latrines (VIP) sludge content. PhD thesis. School of Engineering, Department of Chemical Engineering University of KwaZulu-Natal, South Africa

Bakare BF, Nwaneri CF, Foxon KM, Brouckaert CJ and Buckley CA (2012). Variation in VIP latrine Sludge Contents. Water SA 38 (4) 479–486

De Boer W., Folman L.B., Summerbell R.C. and Boddy L. (2005). Living in a fungal world: impact of fungi on soil bacterial niche development. Federation of European Microbiological Societies. 29 (2005) 795-811

Del Giorgio P.A. and Cole J.J (1998). Bacteria growth efficiency in natural aquatic systems. Annual Review of Ecological system. 29 503-541

Dons A. (1987). Hydrology and sediment regime of a pasture, native forest, and pine forest catchment in the central North Island, New Zealand. NZ Journal of Forestry Science 17 (2/3): 161-78

Duncan M.J. (1993). Does planting pines reduce recharge? New Zealand hydrological annual symposium. NIWA Freshwater, Christchurch, New Zealand

Griffin D.M. (1985). A comparison of the roles of bacteria and fungi In: Bacteria in Nature (Leadbetter E.R. and Poindexerter J.S Eds), Bacterial Activities in Perspective, vol. 1, pp.221-255. Academic Press London.

Jennings D.H. (1987). Translocation of solutes in fungi. Biological Review. 62 215-243

Jönsson H., Richert S.A., Vineras B. And Salomon E. (2004). Guidelines on the Use of Urine and Faeces in Crop Production. EcosanRes Publication Series. Stockholm Environment Institute. Stockholm.

Morgan, P. (2004) An ecological approach to sanitation in Africa – a compilation of experiences, EcosanRes, SEI, Stockholm. http://www.ecosanres.org/PM_Report.htm (accessed 30/01/2012)

Taylor C. (2012-under examination). An investigation into potential of faecal sludge for plant production. Master of Science dissertation. School of Biological and Conservation Science. The University of Kwazulu-Natal. South Africa.

Session A8: Sustainable Drainage Systems

Blue-green infrastructure in highly urbanized areas - practical design examples

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Keywords: green infrastructure, blue-green infrastructure, sustainable drainage systems, SuDS

ABSTRACT

Stormwater management in urban environments has long been based on a simple principle: divert water away from the area as quickly as possible while respecting the safety of residents and property. This was the primary purpose of drainage systems, which is still in many cases. However, on the threshold of the climate crisis, when many European countries are experiencing droughts that have not been seen in several decades, there is a need to rethink this approach. Water in the urban environment should no longer be a nuisance but a resource. This approach is reflected in a new way of looking at urban drainage, where we seek to use water in partnership with vegetation to mitigate the impacts of climate change (Ballard et al. 2015).

Sustainable urban drainage, green infrastructure, low impact development are all different terms for the same principle: retain as much water as possible, as close to the point of impact as possible. We then try to soak up this water, evaporate it, supply it for use by vegetation, or use it for toilet flushing and other purposes. In this way, we try to approximate the natural hydrological cycle in each environment as closely as possible. However, in urban environments, paved surfaces often predominate, and it is often impossible to use green infrastructure features such as green roofs, rain gardens, and bioswales. In such environments, underground concrete tanks and retention galleries are often used as part of the traditional approach, allowing us to retain rainwater and discharge it in a regulated manner. While these elements protect the technical infrastructure from overloading, improve runoff quality, and may even contribute to water storage, they do not bring any additional benefits.

However, even in highly urbanized environments, significant retention of rainwater can be achieved, and at the same time, it can be used for vegetation, which provides essential ecosystem services. A gravel retention system based on the Swedish blue-green-gray (BGG) system allows water retention and tree growth support even in areas where most surfaces are impervious (Fridell et al. 2020). The basis of such a system is an open subbase layer made of coarse crushed aggregate, which has a high porosity and sufficient bearing capacity. Due to the high porosity, water is quickly distributed and retained in such an underground space during a rainfall event, and at the same time, there is good air exchange, which trees in cities often lack. The compactibility and sufficient bearing capacity allow pedestrian and vehicular movement over such systems. Combining individual elements into cascades can achieve a capacity for heavy rainfall events.

The first practical example where a BGG system is proposed for rainwater retention while promoting healthy tree growth is the restoration of Škroupovo Square in Česká Lípa (Czech Republic). Currently, the square is a typical poorly maintained urban space whose primary purpose is to provide car parking (see Figure 1). The square primarily comprises impermeable surfaces with small islands of green space. All water is discharged directly into a combined sewer.

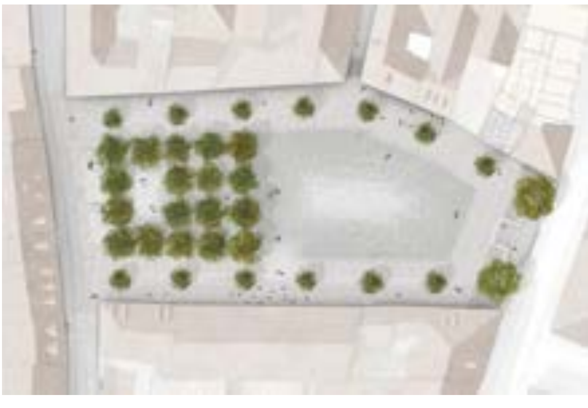
The architectural design of the square makes the space more uncomplicated and accessible to people. Instead of raised green areas with a few trees, more than 30 trees are proposed. However, most of the square is still made up of paving with limited permeability. Despite this, we can retain more than 5-year rainfall from the plaza and the surrounding rooftops, with a regulated discharge of around 1,5 l/s. Smaller rainfall events can be entirely soaked up and used for the vegetation. This is achieved by underground retention spaces filled with gravel, which also serve as a generous root zone area (see picture 3). From

zero, the retention volume at the site will be increased to 90 $m^{3,}$ and the seepage area will be increased to more than 500 m^2.

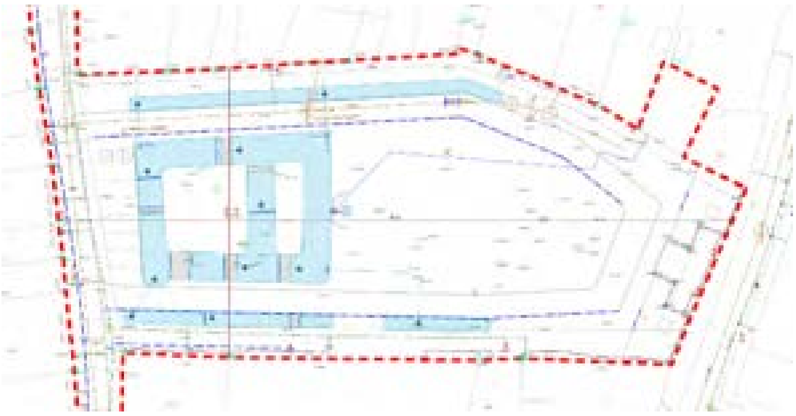
The second example is Zbraslavské Square, the main square of Zbraslav – a city district of Prague. the situation here is similar to the previous example, with the difference that this is a major road junction with high traffic load from public transport buses and individual transport (see picture 4). The architectural design here again emphasizes the movement of people and the addition of greenery along with water features. In this design, water is primarily routed to rain gardens, supplemented by the underground BGG system to increase overall retention capacity and ensure healthy tree growth. Rainwater in this area is discharged unregulated to the stormwater sewer system. In the design, we can retain 10-year rainfall events directly in the area with a regulated discharge of around 2 l/s. There is also a storage tank with a capacity of around 50 m^3. After proper treatment, water from the tank will be used for water fountain refilling and toilet flushing.

As seen from these two examples, nature-based solutions can be effectively used for water management problems even in highly urbanized areas. Not only can we protect the property and ensure a safe and hygienic urban environment, but we can benefit from water if we see it as a valuable resource for various purposes. The healthy growth of trees, which can then (only with enough water) cool our streets, is one of the critical elements of adaptation to climate change in our cities. However, in addition to water, trees also need sufficient underground space for root growth and, what is often forgotten, sufficient fresh air exchange in the root zone area. Using BGG systems allows us to provide all these needs even in paved areas with high pedestrian and car loads. Thus, we can design cities and streets not only for people with their needs but also for the trees.

Picture 1 *Škroupovo náměstí in the city Česká Lípa as an example of a highly impermeable urban space. Currently, the square is mainly used as a parking lot (mapy.cz).*



Picture 2 *The new architectural design of the Škroupovo square (M2AU architects).*



Picture 3 *Underground open subbase retention areas (in blue) also serve as a generous root space for trees (M2AU architects, Grania s.r.o.).*

Picture 4 *Zbraslavské square in the Prague's city district Zbraslav (mapy.cz).*

Picture 5 *Movement of water through Zbraslavské square (atelier tečka architects, Grania s.r.o.)*

References:

Ballard, Bridget Woods; Wilson, Steve; Udale-Clarke, Helen; Illman, Sue; Scott, Tamasine; Ashley, Richard; Kellagher, Richard (2015): The SuDS Manual. London UK: CIRIA (CIRIA, C754).

Fridell, Kent; Thynell, Anna; Bruhn, Frida; Fors, Johan; Sixtensson, Susanne; Vysoký, Martin (2020): Livable Streets - A Handbook of Bluegreengrey Systems. Version 2.0: Edge.

Sustainable drainage systems (SuDS) for rainwater harvesting and stormwater management in temporary humanitarian settlements

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Keywords: Rainwater Harvesting, Refugee Campus, Stormwater Management, Sustainable Drainage Systems, Temporary Humanitarian Settlements

Abstract

Across African refugee camps and temporary shelters, it is very critical to manage stormwater runoff. Sustainable Drainage Systems (SuDS) can be implemented for providing potential sources of water resources across refugee camps and internally displace people (IDPs). The performance of two SuDS (engineered wetlands and biofilters) was evaluated to assess their effectiveness at reducing levels of pollutants in harvested rainwater and stormwater under simulated environmental conditions of an IDP camp. The SuDS comprised of a matrix of sub-surface bedding materials and filter media. Stormwater quality analysis in line with the WHO and CIRIA standards were carried out over a 61-week period simulating environmental conditions. The SuDS significantly reduced nutrients and organics loading from the influent stormwater. The outflow samples from these SuDS found the concentrations to be well-within the limits of WHO's drinking water standards. However, it is recommended that stormwater be reused for non-potable sources in these conditions.

Experimental Study and Modelling of Granular Filter Media used within SuDS for Stormwater Purification

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Keywords: stormwater treatment systems, Sustainable Drainage Systems (SuDS), granular filter media, experimental study, modelling, water pollutant removal efficiency

Abstract

Stormwater treatment systems such as sustainable drainage systems (SuDS) play a crucial role in protecting water resources by removing pollutants from urban runoff. Granular filter media are commonly employed in these systems due to their high stormwater treatment efficiency and cost-effectiveness. This paper presents an experimental study and modelling approach to enhance the understanding of the filtration processes within granular filter media utilised in SuDS for stormwater treatment systems. The experimental study involved characterising the physical and hydraulic properties of various granular filter media materials, including sand, pea-gravel, gravel, and geotextile membranes. Three laboratory-scale stormwater filtration rigs were tested to evaluate the pollutant removal capacity and hydraulic performance of the filter media. This work presents a phenomenological model of three granular stormwater filter, which predicts the spatial variation of concentration of stormwater and urban runoff substances and parameters– of nitrates (NO_3), phosphate (PO_4) ions, chemical oxygen demand (COD) and suspended solids, studying the concentration profiles. The model was used to evaluate the 3 stormwater filters and also the effect of implementing geotextile membranes in a granular filter. The stormwater quality model was used to predict the concentration profiles for stormwater average inflow consisting of 2.9 mg/L nitrates, 3.4 mg/L phosphate ions, 225 mg/L COD, and 3.3 mg/L of suspended solids. The predicted outlet concentrations matched well with measured experimental data. The results showed that adding geotextile membranes to a granular filter significantly improves its ability to adsorb dissolved species for stormwater applications. The experimental results formed the basis for developing a mechanistic model that describes the filtration processes within the granular filter media. The model incorporates key parameters such as media properties, flow rate, pollutant concentrations, and contact time. By utilizing computational algorithms, the model enables the prediction of pollutant removal efficiencies and hydraulic performance under various operating conditions. This research highlights the importance of understanding the physical and hydraulic properties of granular filter media and their impact on stormwater pollutant removal efficiency. The developed model can assist in the design and optimisation of stormwater treatment systems by predicting the performance of different filter media materials, allowing for informed decision-making and improved system functionality.

Assessment of the potential for microplastic retention in mature SUDS.

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Keywords: Microplastic, vegetated swales, urban runoff, bioretention system, soil pollution

ABSTRACT

Introduction

Metropolitan regions and their environs comprise a dense gathering of inhabitants, infrastructure, and economic pursuits that demand significant resources and consequently, impose a severe strain on the environment. The process of urbanization, which is a significant contributor to climate change and pollution, modifies both living and non-living characteristics of ecosystems in and around urban areas, as well as those located far away from them (Grimm et al., 2008). The majority of people in the world live in cities. Currently, 74% of the European population resides in urban areas, and it is expected that this proportion will reach 80% by 2050 (according to AEMA in 2019). According to a recent evaluation of the Directive on Urban Wastewater Treatment, discharges of stormwater and overflows from combined sewer systems account for around 60% of the preventable organic pollution that is discharged into water bodies (Pistochi et al., 2019).

In environmental terms, one of the most critical and current challenges faced by entities responsible for managing stormwater is the issue of plastic pollution, particularly concerning microplastics (MPs), which are plastic particles measuring less than 5 mm. The pollution caused by MPs is one of the most pressing global environmental concerns, causing harm to ecosystems and reducing the services they provide to society. This is why the search for solutions to prevent their release into the environment and their degradation is crucial to address this issue.

Current urban areas are characterized by a high proportion of impermeable surfaces. As a result, during rainy periods, a large volume of surface runoff is generated, which flows towards the sanitation systems, many of which are combined. During particularly heavy rain periods, there is a high probability of combined sewer overflow (CSO). The discharge of CSO has an extremely adverse effect on the receiving environments. This is because they release mixtures of wastewater and stormwater, which can lead to problems of anoxia and eutrophication in the receiving water bodies, as well as the accumulation of debris (such as wipes, paper, and plastic) from both domestic wastewater and street litter. That is why new approaches are needed, such as nature-based solutions, to create new infrastructure that is multifunctional and provides multiple values, such as Sustainable Urban Drainage Systems (SUDS). SUDS have the ability to assist in managing flood risk and water quality. In addition, they can improve biodiversity and the livability of the urban environment (Raymond et al., 2017).

One of the main objectives of the research presented here is to analyze the long-term performance of mature SUDS in retaining MPs, from a hydrological and environmental perspective.

So far, much of the scientific research has been focused on evaluating the effectiveness of urban wastewater treatment plants (WWTPs) in removing MPs and examining the fate of MPs throughout the various stages and components of WWTPs. However, there is limited research on runoff and nature-based solutions, such as SUDS, which can prevent the release of MPs into the environment. To date, only a few urban wetlands and bioretention systems for stormwater management have been evaluated and have demonstrated their ability to retain MPs (Mbachu et al., 2022).

In this case of study, vegetated swales will be specifically studied, which is a particular SUDS technology that consist of channels that are designed to store and/or transport surface water. They can be constructed to allow infiltration in suitable conditions. Their design should facilitate slow water flow, which aids in the settling of suspended particles in stormwater runoff, leading to effective removal of pollutants. Swales along roadsides can be used instead of conventional drainage pipes and gullies (Woods-Ballard et al. 2015).

The purpose of this study is to examine the ability of mature vegetated swales, to remove MPs from urban runoff. To accomplish this task, two systems constructed over a decade ago in the municipality of Xàtiva, in the province of Valencia (Spain), will be evaluated (see Fig. 1).

Figure 13 Current state of the vegetated swales under study. Left: North Roadway swale, right: Sport Area swale

Methodology and results

Soil and vegetation samples are being collected at various points of the infrastructure that are covered with vegetation in the areas alongside the road. They are then being examined to determine the quantity of MPs present. The information obtained will be used to assess the total amount of MPs that have accumulated in the infrastructure since its construction. The results distinguish between microplastics (MPs), particles smaller than 5 mm, mesoplastics (MEPs) (Fig. 3), particles ranging from 5 to 25 mm, and macroplastics (MAPs) (Fig. 2), all the large plastics found in different locations. Additionally, water samples that are representative of the inflow and outflow of the systems during different rain events will be collected. This will allow describing the behavior of water under these specific circumstances and comparing it to the findings on plastics in other studies of urban runoff.

Figure 2 Macroplastics present *in situ* and those sampled in the laboratory for analysis at each sampling point

Figure 3 Mesoplastics collected in soil samples from the swales were isolated in glass jars for analysis (left).

Microplastics were observed under a microscope in the soil samples: plastic fibers (center) and transparent particles (right)

Tables 1 and 2 present the results obtained regarding the analysis of MAPs, MEPs and MPs, respectively, found in soil samples.

Table 6 Macroplastics and mesoplastics identified at each sampling point in the studied vegetated roadside swales. MEPs expressed as MPs per kilogram of dry soil weight

Sample	MAPs Total	MAP/m2	MEPs/kg dw
SA1	27	4.5	8.50
SA2	27	4.5	200.83
SA3	65	5.2	20.38
NR1	20	6.67	11.81
NR2	116	38.67	22.24
NR3	10	3.33	343.17

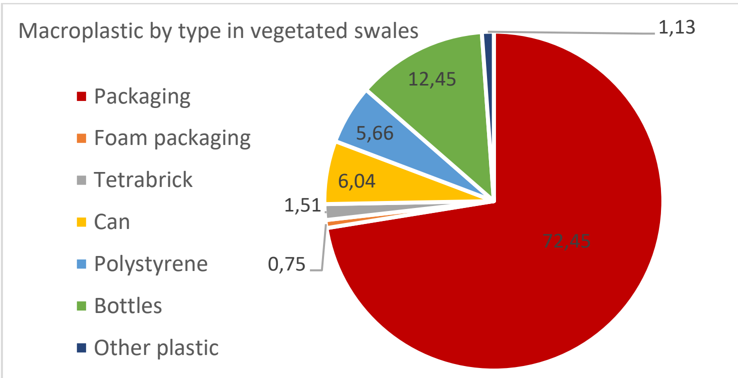

Figure 4 Total macroplastics found by type in both vegetated swales

In this case, two different vegetated swales were studied, one located inside a sports complex named Sport Area (SA), and the other one located adjacent to a major road in the area, designated as North Roadway (NR) (see Fig. 1). At both sampling points, different areas within the swale were identified, including an initial area (point 1) located at the top, an intermediate area (point 2), and a final area (point 3) located near the outlet chambers for both SUDS. One noteworthy point is the intermediate area (point 2) of the NR ditch, which is located next to a unique element installed in the ditch, a discontinuous wall designed to allow pedestrian access and to create a backwater for the water flow. The gaps in the wall allow water to flow through, but the walls themselves act as significant plastic retention structures, as evidenced by the large number of MAPs collected at this sampling point (see central image in Figure 2). Furthermore, point 3 of the SA swale, located at the end of the swale's own pipeline and where a retention pool is formed before entering the final chamber, has a much larger collection surface for plastics, making it a potentially significant retention point for them.

Regarding the overall percentages of MAPs found, the presence of packaging stands out as the main category, representing 72.5% of the total samples (see Fig. 4), while bottles constitute a significant 12.5% of the total. These findings are consistent with global plastic production data, which indicate that 44% of plastic production is intended for packaging, being the largest category of production, followed by plastics used in construction and building, which represent 18% of production and may also be contributing to the category of wrappers found in the samples (PlasticsEurope, 2021).

Table 2 Microplastics found in the various sampled soil points of the studied vegetated ditches and expressed as MPs per kilogram of dry soil weight

Sample	Fibers	Films	Particles	MPs/kg dw
SA1	10	0	15	4533.62
SA2	10	20	4	7412.45
SA3	16	1	1	3545.34
NR1	5	3	9	3218.82
NR2	6	2	4	2300.49
NR3	10	2	4	3147.25

As shown in Table 2, it can be observed that fibers are the most commonly found shape among all samples. This could be attributed to their greater mobility when exposed to environmental agents such as wind or water flow within the roadside ditches. Additionally, there is no direct relationship observed between MAPs and MPs, as a considerable amount of time may elapse in the plastic cycle before macroplastics become microplastics. The most contaminated soil was found in the vegetated swale of the Sports Area, which was expected to have lower concentrations given that it is an area less exposed to traffic and also enclosed by a fence facing the street. It is worth noting that many of the MAPs found in the vegetated swale of North Roadway, particularly in zone 2, came directly from construction worksites adjacent to the ditch (i.e., cement bags, paint cans, construction product containers).

Conclusion

The initial results of this study highlight the importance of the problem associated with the presence of microplastics in urban runoff. A significant amount of these contaminants has been observed in SUDS infrastructure built more than ten years ago, indicating that urban runoff is a significant source of microplastics. The next steps of the research will focus on assessing the potential of these nature-based solutions to retain and biodegrade microplastics, with the ultimate goal of preventing their progression towards receiving bodies.

Acknowledgements

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References:

AEMA, 2019. Urban sustainability: how can cities become sustainable? Retrieved from. https://www.eea.europa.eu/themes/sustainability-transitions/urban-environment/urban-sustainability

Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X., & Briggs, J. M., 2008. Global change and the ecology of cities. science, 319(5864), 756-760.

Mbachu, O., Kaparaju, P., & Pratt, C., 2022. Plastic pollution risks in bioretention systems: a case study. Environmental Technology, 1-14.

Pistocchi, A., 2020. A preliminary pan-European assessment of pollution loads from urban runoff. Environmental research, 182, 109129.

PlasticsEurope, 2021. Plastics - the Facts 2021. Retrieved from. https://plasticseurope. org/knowledge-hub/plastics-the-facts-2021/.

Raymond, C. M., Frantzeskaki, N., Kabisch, N., Berry, P., Breil, M., Nita, M. R., ... & Calfapietra, C. (2017). A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. Environmental Science & Policy, 77, 15-24.

Woods-Ballard, B., Kellagher, R., Martin, P., Jefferies, C., Bray, R., & Shaffer, P., 2007. The SUDS manual (Vol. 697). London: Ciria.

Session A9: Circular water economy

Water companies and circular economy ; Challenges and opportunities

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Keywords: water companies, circular economy, European Union

ABSTRACT

Circular economy entails gradually decoupling economic activity from the consumption of finite resources and environmental degradation. It replaces the end-of-life concept with restoration, eliminates the use of toxic chemicals that impair reuse and return to the biosphere, and aims to eliminate waste through superior design—of materials, products, systems, and business models. Through the transition to renewable energy sources and a more sustainable use of biodiversity and ecosystems, the circular model builds economic, natural, and social capital.

Operating within the context of circular economy principles adopted by the European Union, the water industry in Greece, as well as in entire Europe, faces a time of change. Operation shifts to impoved quality for drinking water and wastewater discharges leading to enhanced environmental protection , a focus on emerging pollutants and a risk-based approach to minimize treatment requirements, to the reduction of waste and the preservation of finite resources through treated wastewater and municipal sludge reuse and nutrient recovery from wastewater, energy neutrality and GHG monitoring and reduction . At the same time water companies should show operational resilience, transparency and accountability, minimize costs and resources use through leakage assessment and reduction and energy consumption minimization while cost recovery becomes a prerequisite for funding and operational competence.

The legal framework comprising the new EU Directive 2020/2184 on the quality of water for human consumption, EU Regulation 2020/741 on the minimum requirements for water reuse , the revision of EU Directive 91/271 which is underway and the new JMD on the use of sewage sludge in agriculture and landscape restoration sets new challenges for the water industry in line with circular economy principles. The National Climatic law requires yearly energy and GHG emission audits and a 30% reduction for GHG emissions between 2019-2030 for WWTP's over 100,000 p.e. Directive 91/271 on urban wasterwater treatment is in the last stages of revision, demanding wastewater treatment for all settlements over 1,000 p.e , introducing limit values for micropollutants in treated wastewater, quaternary treatment for large WWTP's, very strict limit values for nutrient discharges, and setting new goals for WWTP'S energy neutrality by 2040, sludge and water reuse and urban runoff management. Risk assessment and management is introduced in the entire water cycle comprising the water resources catchement area , the water distribution network and the wastewater and sludge reuse, in an effort to minimize waste and pollution, while optimizing energy consumption through treatment reduction, and preserving and enhancing the natural capital of water.

New circular economy practices are incorporated in water companies investments , such as energy upgrades , leakage reduction, renewable energy production (mainly solar) , smart water metering and nutrient recovery. While large scale water reuse is still very limited in Greece a substantial number of projects of WWTP's upgrades for water reuse are under development . Direct sludge reuse in agriculture and co-composting is estimated to be about 20% of total sludge produced , sludge reuse in the cement industry corresponds to about 40% of total sludge produced in Greece while electricity production from anaerobic sludge treatment (biogas) is practiced in a few large WWTP's. Multiple tertiary treatment projects producing water suitable for irrigation with substantial energy reduction or net zero energy as a prerequisite for funding are under development, while 40.000 MWh/year energy saving projects through renewable energy sources and energy efficiency measures and 19 municipal mainly solar sludge drying projects amounting to about 30% of the total sludge produced, are in progress, financed by national and European funds (R.R.F., A.Tritsis, Filodimos funds).

In the WWTP of Chania, 15% of the energy consumption is covered by electricity produced from sludge anaerobic digestion biogas, with a target of increasing renewable energy production through the installation of photovoltaic stations of 600 KW by 2025. Towards finding a sustainable and cost-effective solution to the longstanding issue of sludge management, D.E.Y.A.Ch. partnered with the Technical University of Crete in a joint research project that is currently ongoing. The project is funded by the Green Fund of Greece and deals with the pilot testing the green technology of Constructed Wetlands for sludge dewatering to determine the efficiency, optimize the technical parameters and demonstrate the environmental and financial benefits of this sustainable nature-based solution.

Water recovery in swimming pools in accordance with the assumptions of the circular economy

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Keywords: rainwater, sustainable development, circular economy, pollution, water quality

ABSTRACT

Research on the occurrence of pollutants in the human environment, in particular the search for sources of their emission, is considered one of the most important issues undertaken as part of protecting and improving the quality of human life (Ren et al., Jahangir et al., Arslan et al, Graça). Sustainable socio-economic development can be achieved only if effective methods of their elimination are developed, ensuring the preservation of public health (Warren-Vega et al., Jayaswal et al., Halder and Islam). One of the greatest challenges in this regard is the constantly deteriorating quality and available resources of water in the environment (Akhtar et al., Khati et al., Shahabudin and Musa). In order to stop the deteriorating quality of water and increase access to water of appropriate quality, it is necessary to obtain current and up-to-date information on the state of the environment. Implementation of new observation methods and tools supporting monitoring and assessment of the condition of aquatic ecosystems must be preceded by accurate and reliable identification of sources of pollution. Only such a sequence of actions will ensure effective achievement of the objectives imposed on Poland by the Water Framework Directive (Directive 2000/60/EC).

The problems related to water resources and deficiencies in water management may become a serious obstacle to the socio-economic development, and the need to adapt urban areas to climate change, taking into account the construction of sustainable systems for the management of rain and snowmelt water, seems to be one of the greatest challenges for the community in the coming years.

The traditional approach to the problem of rainwater management is based on the principle of rapid capture and discharge through rainwater or combined sewer systems to surface waters. Such a solution brings many negative phenomena, both for the drained areas and for the recipients. Cities and metropolitan areas have problems with overloading of drainage systems. As a result of sealed surfaces in urban centers and partly as a result of climate change (including an increase in the frequency and magnitude of heavy rains), the capacity of many combined systems is exceeded. During heavy rains, numerous overflows from the wastewater system occur, as well as activation of rainwater overflows. These overflows occur more frequently than is allowed by law. In areas with traditional storm sewer systems, localized lowering of the water table and excessive drying of the soil occurs. As a result of this phenomenon, there is a local increase in temperature and drying of the air in cities, which has a very negative impact on the health and well-being of the population. The inadequate management of rainwater has a significant impact on the ecological balance, the disappearance of sensitive vegetation and the alteration of soil structure. Traditional sewage systems are increasingly unable to absorb excessive amounts of rainwater due to ongoing urbanization, resulting in flooding of areas and buildings and impeding communications. These problems give rise to an economic problem resulting from the need to reserve a considerable capacity of sewerage networks, which imposes very high investment costs, both in the design of new networks and in the maintenance of existing ones.

Rainwater and meltwater are unfortunately wasted in modern environmental engineering by immediate discharge into receiving waters, although they represent a valuable and free water resource that can be successfully used for many different purposes.

In order to limit the adverse phenomena associated with the discharge of rainwater, new alternative methods of its management are being sought worldwide. The best solution is the retention and reuse of water as close as possible to the place of precipitation. Such an approach is also a response to the challenges of piped water supply. It is possible to replace a certain amount of tap water with rainwater stored and used on site, thus reducing the demand for tap water.

The aim of the undertaken study presented in this paper was the expanded assessment the rainwater quality in terms of its use in swimming pools. The study is guided by the idea of improving the quality of life of people through the development of environmentally friendly technologies.

Environmental samples for analysis were collected from different locations in Poland and were subjected to non-target NTA chromatographic analysis. The identification of micropollutants present in rainwater was carried out by comparing the obtained spectra with reference spectra from the commercial NIST v.17 database. Then, the samples were subjected to a qualitative TA (Target Analysis), i.e. the presence of selected micropollutants from among the most frequently identified previously were confirmed by injection of a standard of a given compound. Due to the lack of reference methods for the determination of organic micropollutants in the aquatic environment, the authors have developed their own procedure in this regard, which includes preparation of a sample for analysis using Solid Phase Extraction Extraction (SPE) and chromatographic analysis carried out using the gas chromatography technique. The developed analytical procedure was validated by determination the linearity of the detector response and the precision and repeatability of the analyses, in detail described in own work Lempart et al. The compounds most commonly identified in testes rainwater samples are presented in Table 1.

Table 1. Frequency of organic micropollutant occurrence in tested rainwater samples

Compound name	Frequency of occurrence in rainwater samples, %
Pentanoic acid	86
Butanoic acid	88
Neodecanoic acid	40
5-tert-butylpyrogallol	58
2,6-dimethoxy-phenol	36
Diisobutyl phthalate	100
Dibutyl phthalate	88
Hexadecane	100
Nonadecane	98
Octadecane	100
Tetradecane	96
Galaxolide	74
Versalide	70
Benzo(a)pyrene	20
Naphthalene	36
Anthracene	10

The conducted research confirmed the hypothesis that there are organic micropollutants present in rainwater not described yet by the available literature data. It has been shown that the quality of rainwater does not allow for its direct use in the swimming pool system, it is required to be pre-treated. The direction of further research by the authors will concern the development of an innovative method of rainwater treatment, which will enable its safe recycling in swimming pool environment.

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References:

Arslan, M., Ullah, I., Müller, J.A., Shahid, N., Afzal, M.,2017. Organic Micropollutants in the Environment: Ecotoxicity Potential and Methods for Remediation. In: Anjum, N., Gill, S., Tuteja, N. (eds) Enhancing Cleanup of Environmental Pollutants. Springer

Akhtar, N.; Syakir Ishak, M.I.; Bhawani, S.A.; Umar, K., 2021. Various Natural and Anthropogenic Factors Responsible for Water Quality Degradation: A Review. Water 13, 2660, https://doi.org/10.3390/w13192660

Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000

Graça, C.A.L., 2023. Research on Micropollutants in Urban Water. Water, 15, 644, https://doi.org/10.3390/w15040644

Halder J., Islam N., 2015. Water Pollution and its Impact on the Human Health, Journal of Environment and Human 2, 36-46, https://doi.org/10.15764/EH.2015.01005.

Jahangir A., Shoaib N., Munir A.,et at. 2019. A critical review on organic micropollutants contamination in wastewater and removal through carbon nanotubes, Journal of Environmental Management 246, 214-228, https://doi.org/10.1016/j.jenvman.2019.05.152

Jayaswal, K., Sahu, V., Gurjar, B.R., 2018. Water Pollution, Human Health and Remediation. In: Bhattacharya, S., Gupta, A., Gupta, A., Pandey, A. (eds) Water Remediation. Energy, Environment, and Sustainability. Springer, Singapore. https://doi.org/10.1007/978-981-10-7551-3_2

Khati N. Tyagi S., 2015. Influences of natural and anthropogenic factors on surface and groundwater quality in rural and urban areas. Frontiers in Life Sciences, 8, 23-29, https://doi.org/10.1080/21553769.2014.933716

Lempart A., Kudlek E., Dudziak M., 2018. Determination of micropollutants in water samples from swimming pool systems. Water 10, 1083, https://doi.org/10.3390/w10081083

Ren, H., Tröger, R., Ahrens, L. et al. 2020. Screening of organic micropollutants in raw and drinking water in the Yangtze River Delta, China. Environmental Sciences Europe 32, 67, https://doi.org/10.21203/rs.2.19861/v2

Shahabudin M. M., Musa S., 2018. Occurrence of Surface Water Contaminations: An Overview. IOP Conference Series: Earth and Environmental Science 140, 012058, https://doi.org/10.1088/1755-1315/140/1/012058

Warren-Vega, W.M.; Campos-Rodríguez, A.; Zárate-Guzmán, A.I.; Romero-Cano, L.A., 2023. A Current Review of Water Pollutants in American Continent: Trends and Perspectives in Detection, Health Risks, and Treatment Technologies. International Journal of Environmental Research and Public Health 20, 4499 https://doi.org/10.3390/ijerph20054499

Water quality monitoring of recycled water using effect-based bioassays – a tool for the circular economy

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Keywords: effect-based analysis, planar-bioassay, water quality assessment, estrogenicity, profiling, early-warning method

ABSTRACT

In the context of circular economy, the recycling of water increases in importance. However, a multitude of unwanted, harmful substances may be recycled together with recycling water. This poses a potential safety threat for users and consumers of the recycled water. At the example of 26 Swiss wastewater treatment plants (WWTP), we tested the novel planar Yeast Estrogen Screen, an effect-based bioassay. In 22 of the 26 WWTPs, estrogenic activity was detected. In several cases, up to six different estrogenically active responses were found. We consider this approach may become a key-element of a future early warning system for the quality assessment of recycled water.

INTRODUCTION

Effect-based analysis (EBA) is emerging as a crucial element in water quality monitoring, complementing traditional chemical analysis methods. EBA methods are using bioassays which are measuring the biological response of organisms exposed to potentially contaminated samples. The application of EBA to water samples is a promising element that acts as early-warning method for water pollution risks.

A key advantage of EBA is its potential to detect critical substances, or critical metabolites of harmless substances, without the need to know the trigger chemicals. The Yeast Estrogen Screen YES (Routledge & Sumpter 1995, McDonnell et al. 1991)), for example, relies on genetically modified yeast cells that bear with them the human estrogen receptor. If an estrogenic substance gets in contact with this estrogen receptor, a cascade of reactions triggers a response.

The novel planar-YES, which has been co-developed by ZHAW, combines a) the sample separation using thin-layer chromatography (TLC) with b) the YES bioassay (Schoenborn & Grimmer, 2013; Spira et al. (2013), Schoenborn et al., 2017). The sensitivity of the planar-YES is ca. 100x more sensitive than the current standardized YES (Bergman et al., 2020).

The results presented here, were collected in a field study focused on estrogenic activity in treated wastewater. The aim was to demonstrate the potential of the planar-YES bioassay for a holistic the assessment of estrogenic activity in water samples.

EXPERIMENTAL SETUP

The aim of the field study was to profile estrogenic activity in treated wastewater and explore possible typification. For this, 42 wastewater samples (24-hour composite samples) were collected from 26 different wastewater treatment plants (WWTP) in the Swiss Cantons of Zurich and Thurgau, in 2016. The unfiltered samples were concentrated 138-fold by using liquid-liquid extraction, and then analysed on estrogenic activity (EA), by using the planar Yeast Estrogen Screen (YES) bioassay (Schoenborn et al. 2017). The planar-YES was conducted on normal-phase high-performance thin-layer chromatography (HPTLC) plates. The results were expressed as equivalents of 17-beta-estradiol (EEQ).

RESULTS AND DISCUSSION

In 22 of the 26 WWTP at least one EA-zone was detected. Some samples showed up to 6 different EA-zones. The profiles were assigned to four distinct general types of profiles. Based on known Rf-values, most of the EA-zones were attributed to 17-beta-estradiol (E2), 17-alpha-ethinylestradiol (EE2) and estrone (E1). However, also four active EA-zones with hitherto unknown Rf-values origin were found in the WWTP outlets. The highest single EEQ value found was 1.6 ng/l EEQ, while the highest sum of all detected EEQ values was 2.6 ng/l EEQ. This EEQ concentration is several times higher than the proposed chronic quality standard for E2 of 0.4 ng/l (Ecotox Center, undated).

Some EA-profiles were found to be stable on two consecutive days, while others varied from day to day. The reasons for these variations were unknown. The profiles were assumed to be related to the size of the WWTP and their catchment. We were also able to show that the planar-YES can be useful for assessing the effectiveness the fourth treatment stage of WWTPs, which it is currently implemented in Swiss WWTPs.

CONCLUSION

This study shows that the planar-YES is a relatively simple and sensitive tool to screen unknown water samples on estrogenic activity and get some clues about its possible origin. The procedure that was used in this study can also easily be extended to other types of water, such as greywater, irrigation water, or recycled process water, e.g., from industry. It can also be used for assessing technologies used for removing microcontaminants from wastewater, thus assisting technology development. Last, but not least, planar bioassays can also be performed with other toxicological endpoints, e.g., genotoxicity with the umuC bioassay (e.g., Riegraf et al. 2021) , with the Yeast Androgen Screen (YAS) or other bioassays.

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REFERENCES

A.J. Bergmann, E. Simon, A. Schifferli, A. Schönborn, E.L.M. Vermeirssen, 2020, Estrogenic activity of food contact materials—evaluation of 20 chemicals using a yeast estrogen screen on HPTLC or 96-well plates, Analytical and Bioanalytical Chemistry https://doi.org/10.1007/s00216-020-02701-w

D.P. McDonnell, Z. Nawaz, C. Densmore, N.L. Weigel, T.A. Pham, J.H. Clark, B.W. O'Malley (1991), High level expression of biologically active estrogen receptor in Saccharomyces cerevisiae. The Journal of Steroid Biochemistry and Molecular Biology 39 (3):291-297

E.G. Routledge, J.P. Sumpter (1995), Estrogenic activity of surfactants and some of their degradation products assessed using a recombinant yeast screen. Environmental Toxicology and Chemistry, Vol. 15, No. 3, pp. 241–248

A. Schönborn, A., Grimmer, 2013, Coupling sample preparation with effect-directed analysis of estrogenic activity - Proposal for a ne rapid screening concept for water samples, JPC - J. Planar Chromatogr. - Mod. TLC. 26 (2013) 402–408. doi:10.1556/JPC.26.2013.5.3.

A. Schönborn, P. Schmid, S. Bräm, G. Reifferscheid, M. Ohlig, S. Buchinger, Unprecedented sensitivity of the planar yeast estrogen screen by using a spray-on technology, J. Chromatogr. A. 1530 (2017) 185–191. doi:10.1016/j.chroma.2017.11.009.

D. Spira, G. Reifferscheid, S. Buchinger (2013) Combination of high-performance thin-layer chromatography with a specific bioassay - A tool for effect-directed analysis. JPC - Journal of Planar Chromatography - Modern TLC 26 (5):395-401. doi:10.1556/jpc.26.2013.5.2

C. Riegraf, G. Reifferschei, L. Moscovic, D. Shakibac, H. Hollert, S. Belkin, S. Buchinge. 2021, Coupling high-performance thin-layer chromatography with a battery of cell-based assays reveals bioactive components in wastewater and landfill leachates. Ecotoxicology and Environmental Safety 214 (2021) 112092

Ecotoxcenter (undated), Proposals for Quality Criteria for Surface Waters, https://www.ecotoxcentre.ch/expert-service/quality-criteria/quality-criteria-for-surface-waters?_ga=2.23605306.1270048670.1689456936-972877019.1689456936 (visited July 16, 2022)

Greywater treatment and reuse in a residential building in Zurich, Switzerland: Evaluation of the treatment performance and user acceptance

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Keywords: Greywater reuse; horizontal flow constructed wetland; treatment efficiency; user acceptance

ABSTRACT

Reusing greywater as an alternative water source is gaining traction amid increasing water stress around the world. The objective of this case study was to investigate a horizontal flow constructed wetland (HFCW) greywater treatment system installed at a residential building in Zurich, Switzerland, which is designed to reuse the treated greywater for toilet flushing. The system was evaluated based on the treatment efficiency of the HFCW and the water quality of the treated greywater; the potential water, energy and financial savings; as well as the user acceptability of reusing treated greywater for toilet flushing and garden irrigation. The HFCW showed acceptable removal efficiencies for COD (93.8%), TOC (78.9%), PO_4 (74.4%), turbidity (76.6%), NH_4 (76.8%), TN (46.9%), E. coli (LR 3.65), total Coliforms (LR 2.77), Enterococcus (LR 3.29), Total Viable Count (LR 3.05) and P. aeruginosa (LR 3.50). However, the treated water effluent did not consistently meet the water quality standards of the guidelines assessed. It is recommended that the system be retrofitted with a sediment filter and disinfection step to improve the water quality.The water balance showed that the system is capable of handling the water demand for toilet flushing and irrigation. The specific energy consumption (5.21 kWh/m^3) was higher than values reported in the literature. Through the evaluation of avoided costs for water and the costs for energy consumption, cost savings could be determined. The results of the user acceptance study showed that 67% of the survey respondents were satisfied with the greywater treatment system. Moreover, 100% of respondents were in favor of using recycled greywater for toilet flushing and garden irrigation. The drawbacks experienced most frequently by the users were deficient aesthetics of the water and staining of the toilet by sediment.

INTRODUCTION

Water stress is a reality in many parts of the world and this phenomenon is destined to worsen in the coming years due to the effects of climate change as well as an expected increase in water demand (Collivignarelli et al., 2020). Since greywater is produced on a daily basis, it represents a consistent source for water collection. Therefore, there is a large potential to recycle and reuse this water. Currently, the most commonly described application for greywater reuse in the literature is for toilet/urinal flushing (De Gisi et al., 2016; Zhu et al., 2018), which can achieve a reduction in water demand of between 10-30% (Friedler et al., 2005). However, water reuse for toilet flushing has also been associated with negative feedback, such as undesired odor and color (Narasimhan et al., 2006) as well as potential health risks resulting from microbial regrowth (Jjemba et al., 2010). This negative feedback also plays a role in the public acceptance of greywater reuse, as the level of satisfaction regarding greywater recycling systems has been found to be related to the performance of the system (Domènech & Saurí, 2010).

MATERIALS AND METHODS

Following chemical and physical water parameters were measured on-site with a portable multimeter and turbidimeter (Hach Lange): dissolved oxygen (DO), electrical conductivity (EC), potential hydrogen (pH), temperature and turbidity. The chemical oxygen demand (COD), phosphate (PO_4), ammonium (NH_4), nitrite (NO_2), and nitrate (NO_3) were analyzed in the lab using a spectrophotometer (Hach Lange). The total nitrogen (TN) and total organic carbon (TOC) were measured with the TOC-L/TNM-L analyzer (Shimadzu). For the total suspended solids (TSS) a standard gravimetric procedure (APHA, 2005) was used for analysis. The total viable count, E.coli, total coliforms, and Enterococcus were analyzed using a sterile filtration technique and CompactDry plates (NISSUI), and for the P.aeruginosa analysis, the samples were directly spread onto Agar plates (Biomérieux). The plates were incubated for 24 hours at 35°C. Finally, Legionella spp. in the greywater and treated water were also analyzed by an external laboratory twice during the sampling period. The sampling took place between the months of January and May 2023.

At present, there are no guidelines for the reuse of greywater at an international level, nor does Switzerland have a national guideline (*Greywater [Factsheet]*, 2021). Instead, the treated water was compared to the Swiss Ordinance on Drinking and Bathing Water (TBDV, 2016), the Swiss Waters Protection Ordinance (WPO, 1998), and a selection of guidelines for greywater reuse from other countries.

For the water balance, the theoretical consumption of treated water for toilet flushing and irrigation was calculated based on the percentage distribution of water consumption of an average Swiss household (*Greywater [Factsheet]*, 2021) using the actual total consumption of drinking water in the case study house. The amount of greywater produced was measured. Additionally, daily precipitation and evapotranspiration data was obtained from the MeteoSwiss data portal for teaching and research (IDAweb - MeteoSwiss).

For the energy balance, the electrical current of the system's components was measured from the fuse box using the FLUKE 1738 Three-Phase Power Quality Logger over a period of two weeks. The energy consumption was then calculated using the average current.

For the cost evaluation of the HFCW system, the avoided costs of the treated water that could be reused for toilet flushing and irrigation and the costs for the energy consumption of the system were taken into account.

To assess the user acceptance, an online survey was developed and sent to the inhabitants at the case study house (N=17) by email. The survey was composed as a quantitative assessment, including 2 comprehension questions, 15 Likert scale questions (Likert, 1932), and 2 frequency questions.

RESULTS AND DISCUSSION

The highest mean removal efficiency was found for COD (93.8%), followed by TOC (78.9%), PO_4 (74.4%), turbidity (76.6%), NH_4 (76.8%) and TSS (63.4%). TN showed the lowest mean removal efficiency (46.9%). These removal efficiencies are comparable to other literature values, except for TSS, which was lower than in other HFCW case studies (Vymazal, 2002). The mean removal efficiency for all microbiological parameters was above 2 log reduction, thus indicating removal efficiencies of 99% or higher. These results are also within the same range of removal efficiencies reported in a review paper, however, the total number of microbes in both the greywater influent and the treated water effluent were significantly higher for this case study than those for other HFCW systems (Arden & Ma, 2018).

The treated water effluent did not consistently meet the water quality standards of the guidelines assessed in this thesis. It is highly recommended that a disinfection be added to the system for future use, as is suggested by various sources for reuse of greywater for domestic purposes, in order to limit the risks of pathogens (EPA, 2004; Health Canada, 2010; PUB, 2014; WHO, 2006). Additionally, a sediment filter could reduce the level of turbidity and suspended solids in the system.

The greywater production was measured at 768 L/d and a theoretical consumption of treated water was calculated to be 575 L/d. This indicates that the system operates with a water surplus. Since, the production of greywater as well as the consumption of the treated water depends on the living habits of the inhabitants (Li et al., 2009), these values may fluctuate, however, the water balance showed that the HFCW system is capable of handling the water demand for toilet flushing and irrigation for this case study. The SEC of the HFCW system was calculated to be 5.21 kWh/m^3. Compared to a literature value of 0.16 kWh/m^3 for aerated subsurface flow wetlands (Kadlec & Wallace, 2008), the energy consumption intensity of the case study is much higher. Finally, financial savings of 453.46 CHF/year were calculated. This is achieved through the operational costs for the energy consumption being lower than the costs that were avoided through the reuse of treated water. Labour costs for maintenance work was not included in the calculation.

In the user acceptance study, it was found that the drawbacks that were experienced most frequently with the system were “deficient water aesthetics” and “staining of the toilet by sediment” (see Figure 1). However, there does not seem to be a concern from the inhabitants regarding health risks. This could be due to the relatively low level of human contact when using the recycled greywater for toilet flushing (Dolnicar & Schäfer, 2009). When asked about potential uses of recycled greywater the respondents would find acceptable, “toilet flushing in own household” and “garden irrigation” both received 100% “very acceptable” responses. This indicates that the inhabitants agree with the scope of the greywater reuse in their own house. Additionally, it seems that the closer the recycled greywater were to get to human contact (such as showering, cooking, and potable use), the less favourable the opinions on reuse become. This is in line with results from previous studies (Dolnicar & Schäfer, 2009). The overall level of satisfaction with the system was higher (66.7%) than the level of dissatisfaction (33.3%).

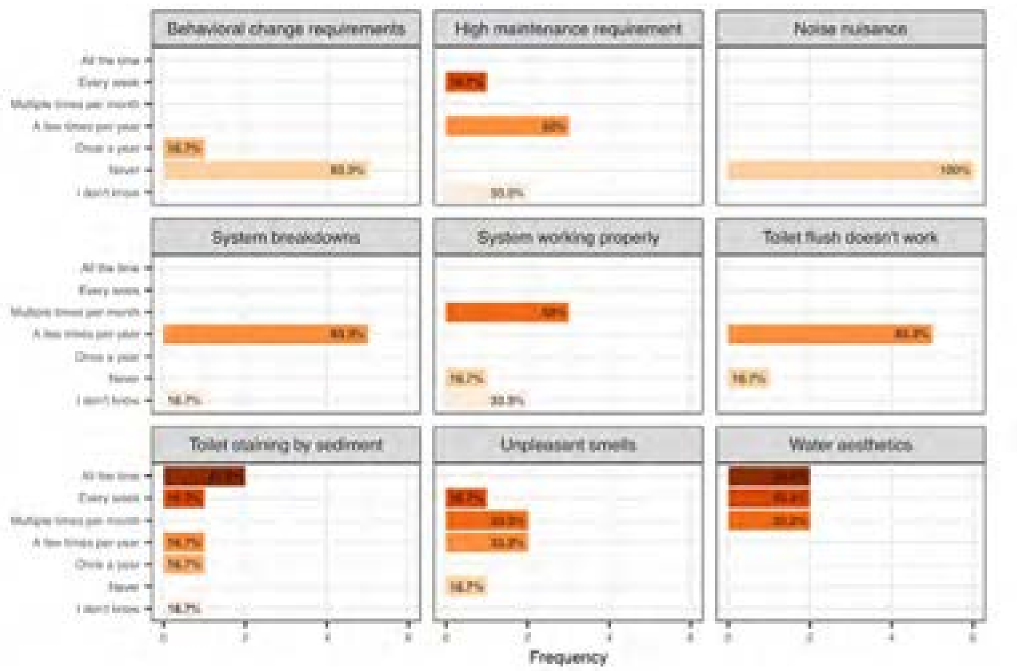

Figure 14: Drawbacks of the case study HFCW greywater treatment system experienced by users

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References

APHA. (2005). *Standard Methods for the Examination of Water and Waste Water* (Method 2540 D; 21st Edition).

Arden, S., & Ma, X. (2018). Constructed wetlands for greywater recycle and reuse: A review. *Science of The Total Environment*, *630*, 587–599. https://doi.org/10.1016/j.scitotenv.2018.02.218

Collivignarelli, M. C., Carnevale Miino, M., Gomez, F. H., Torretta, V., Rada, E. C., & Sorlini, S. (2020). Horizontal Flow Constructed Wetland for Greywater Treatment and Reuse: An Experimental Case. *International Journal of Environmental Research and Public Health*, *17*(7), Article 7. https://doi.org/10.3390/ijerph17072317

De Gisi, S., Casella, P., Notarnicola, M., & Farina, R. (2016). Grey water in buildings: A mini-review of guidelines, technologies and case studies. *Civil Engineering and Environmental Systems*, *33*(1), 35–54. https://doi.org/10.1080/10286608.2015.1124868

Dolnicar, S., & Schäfer, A. I. (2009). Desalinated versus recycled water: Public perceptions and profiles of the accepters. *Journal of Environmental Management*, *90*(2), 888–900. https://doi.org/10.1016/j.jenvman.2008.02.003

Domènech, L., & Saurí, D. (2010). Socio-technical transitions in water scarcity contexts: Public acceptance of greywater reuse technologies in the Metropolitan Area of Barcelona. *Resources, Conservation and Recycling*, *55*(1), 53–62. https://doi.org/10.1016/j.resconrec.2010.07.001

Verordnung des EDI vom 16. Dezember 2016 über Trinkwasser sowie Wasser in öffentlich zugänglichen Bädern und Duschanlagen (TBDV), 817.022.11 SR (2016). https://www.fedlex.admin.ch/eli/cc/2017/153/de

EPA. (2004). *Guidelines for Water Reuse*. U.S. Environmental Protection Agency.

Friedler, E., Kovalio, R., & Galil, N. I. (2005). On-site greywater treatment and reuse in multi-storey buildings. *Water Science and Technology*, *51*(10), 187–194. https://doi.org/10.2166/wst.2005.0366

Greywater [Factsheet] (p. 4). (2021). Eawag. https://www.eawag.ch/fileadmin/Domain1/Beratung/Beratung_Wissenstransfer/Publ_Praxis/Factsheets/fs_greywater_0221.pdf

Health Canada. (2010). *Canadian Guidelines for Domestic Reclaimed Water for Use in Toilet and Urinal Flushing* (p. 54). Federal-Provincial-Territorial Committee on Health and the Environment.

ISO, I. O. for S. (2007). *Microbiology of food and animal feeding stuffs—General requirements and guidance for microbiological examinations (ISO/FDIS 7218:2007)*. https://www.iso.org/standard/36534.html

Jjemba, P. K., Weinrich, L. A., Cheng, W., Giraldo, E., & Lechevallier, M. W. (2010). Regrowth of potential opportunistic pathogens and algae in reclaimed-water distribution systems. *Applied and Environmental Microbiology*, *76*(13), 4169–4178. https://doi.org/10.1128/AEM.03147-09

Kadlec, R. H., & Wallace, S. (2008). *Treatment Wetlands* (2nd ed.). CRC Press.

Li, F., Wichmann, K., & Otterpohl, R. (2009). Review of the technological approaches for grey water treatment and reuses. *Science of The Total Environment*, *407*(11), 3439–3449. https://doi.org/10.1016/j.scitotenv.2009.02.004

Likert, R. (1932). A technique for the measurement of attitudes. *Archives of Psychology*, *22 140*, 55–55.

MeteoSwiss, F. O. of M. and C. (n.d.). *Data portal for teaching and research (IDAweb)*. Retrieved 1 June 2023, from https://www.meteoschweiz.admin.ch/service-und-publikationen/service/wetter-und-klimaprodukte/datenportal-fuer-lehre-und-forschung.html

Narasimhan, R., Brereton, J., Abbaszadegan, M., Ryu, H., Butterfield, P., Thompson, K., & Werth, H. (2006). *Characterizing Microbial Water Quality in Reclaimed Water Distribution Systems* (p. 321). AWWA Research Foundation.

PUB. (2014). *Technical Guide for Greywater Recycling System* (1st Edition; p. 32). Singapore's National Water Agency. https://www.pub.gov.sg/Documents/greywaterTech.pdf

Waters Protection Ordinance of 28 October 1998 (WPO), 814.201 SR § Annex 3 (1998). https://www.fedlex.admin.ch/eli/cc/1998/2863_2863_2863/en

Vymazal, J. (2002). The use of sub-surface constructed wetlands for wastewater treatment in the Czech Republic: 10 years experience. *Ecological Engineering*, *18*(5), 633–646. https://doi.org/10.1016/S0925-8574(02)00025-3

WHO. (2006). *Overview of greywater management health considerations* (p. 49). World Health Organization, Regional Office for the Eastern Mediterranean. https://apps.who.int/iris/bitstream/handle/10665/116516/dsa1203.pdf?sequence=1&isAllowed=y

Zhu, J., Wagner, M., Cornel, P., Chen, H., & Dai, X. (2018). Feasibility of on-site grey-water reuse for toilet flushing in China. *Journal of Water Reuse and Desalination*, *8*(1), 1–13. https://doi.org/10.2166/wrd.2016.086

Session B1: Resource recovery and reuse from waste

Development of a Beach Management Technology Solution to Monitor and Mitigate Plastic Marine Littering

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Keywords: Plastic marine littering, Circular economy, Unmanned Vehicles, Wireless sensors, Gamification, Behavioral change

ABSTRACT

Plastic marine pollution has emerged as a major concern worldwide, as millions of tons of end up in the oceans every year, causing environmental, economic, health, and aesthetic issues. Plastics' durability is their downfall when it comes to marine littering, as the material can persist in the environment for hundreds of years, slowly breaking down into smaller fragments known as microplastics (Gallo et al., 2018). As a result, their increasing production volume supplied to the global economy is a major cause of marine pollution (Geyer, 2020). Part of the plastic marine pollution comes from fishing and other maritime activities or illegal dumping at sea, but about 80% comes from land-based sources (Li et al, 2016), mainly due to improper waste management practices. As a result, millions of tons of plastic that could become valuable secondary raw materials, end up polluting the beaches, causing immense and long-term damage. Lau et al. (2020) estimate that, even if immediate and coordinated actions take place, 710 million tons of plastic waste will cumulatively enter marine ecosystems between 2016 and 2040, while Lebreton and Andrady (2019) developed scenarios that suggest that the way litter is generated and managed has to be changed completely, in order to for this issue to be resolved. To combat the problem effectively, a range of mitigation strategies and policies have been proposed and implemented, including waste management improvements, recycling initiatives, education and awareness campaigns, and policy interventions (Ogunola et al., 2018). Additionally, advancements in technology provide promising avenues to that end.

The research project presented in this paper aspires to mitigate the repercussions of marine pollution, by providing an engaging and gamified learning experience to the people that visit beaches for recreational activities. The GOLDEN SEAL project develops an integrated technology solution that incorporates numerous new technologies, in order to form an ecosystem dedicated to the monitoring and eliminating of the plastic marine pollution. The data collected by the project's subsystems are used for the development of a serious game, in which the beaches compete with each other, and the game aspires to raise awareness and engage citizens and tourists in cleaning and recycling activities, in order to assist beach operators to keep their areas clean of plastic debris. To that aim, the project's final product is a platform that combines the collected data into a gamified application and inspires individuals to shift their behaviour towards safe disposal of plastic debris and marine environment conservation.

The solution's integrated management methodology is built based on the above-mentioned data that are collected by unmanned vehicles, imaging and environmental sensors and smart bins located in the beach. The data is transferred in the project's specialized web platform, where it is filtered and analysed. The most integral part of the technology solution is the set of unmanned vehicles, one aerial (UAV) and one surface (USV). The vehicles are equipped with state-of-the-art imaging sensors and their daily task is to monitor the beaches participating in the programme. The images collected across the coastline by the two vehicles, on the beach and underwater respectively, are uploaded to the platform, and by using image recognition analysis software, the platform quantifies the plastic debris lying across the coastline every day, in order to identify the littering status and the daily cleaning progress of each beach. Except, the imaging sensors, UAV and USV are also equipped with environmental sensors which are part of a larger Wireless Sensor Network (WSN) based on Internet of Things (IoT) technology that includes land-based and underwater sensors. All environmental sensors collect data about all kinds of pollution (air quality, water quality, noise levels etc.) and the results are utilized for the purposes of the project's serious game to

contribute to the participating beaches dynamic leaderboard. Lastly the overall system is also supported by bins equipped with smart scales, located in the beach premises. This leads to the transformation of the area's waste management system into a system that quantifies the waste that is thrown out by the visitors, both in regular bins and recycling bins.

Along with the use of the aforementioned technologies, which are located centrally within the framework of the Fourth Industrial Revolution (Industry 4.0), the project introduces, as it is already mentioned, a serious game through a mobile application, which is expected to play a cardinal role in the successful outcome of the project. The design of the application serves the purpose of activating citizens through its gamification elements, not only in preserving the marine ecosystem, but also in developing the habit of recycling. Quantification of plastic debris through the imaging sensors and the ratio of the weight of disposed recyclables in recycling bins to the weight of the total waste are used for the development of a point system that leads to several leaderboards. The overall ranking of the game is also affected by the measurements of the environmental sensors. The emphasis is placed on the definition of the gamification methods and elements that are selected to increase user engagement and incentivize them to adopt environmentally friendly attitudes.

Conclusively, GOLDEN SEAL project aims to raise awareness of citizens and tourists visiting beaches against plastic marine pollution, in order to strengthen their recycling habits and prevent waste from entering the marine environment. The need for comprehensive actions is pressing and the integration of scientific research and technological advancements is essential for effectively addressing this global challenge. Nonetheless it is important that every strategy trying to combat this issue should include communities and individuals, as it is crucial to recognize that individual choices and responsible behaviour play a significant role in combating the issue.

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References:

Geyer, R. (2020). Production, use, and fate of synthetic polymers. In Plastic waste and recycling (pp. 13-32). Academic Press.

LI, W. C., Tse, H. F., & Fok, L. (2016). Plastic waste in the marine environment: A review of sources, occurrence and effects. Science of the total environment, 566, 333-349.

Lau, W. W., Shiran, Y., Bailey, R. M., Cook, E., Stuchtey, M. R., Koskella, J., ... & Palardy, J. E. (2020). Evaluating scenarios toward zero plastic pollution. Science, 369(6510), 1455-1461.

Lebreton, L., & Andrady, A. (2019). Future scenarios of global plastic waste generation and disposal. Palgrave Communications, 5(1), 1-11.

Ogunola, O. S., Onada, O. A., & Falaye, A. E. (2018). Mitigation measures to avert the impacts of plastics and microplastics in the marine environment (a review). Environmental Science and Pollution Research, 25, 9293-9310.

Gallo, F., Fossi, C., Weber, R., Santillo, D., Sousa, J., Ingram, I., ... & Romano, D. (2018). Marine litter plastics and microplastics and their toxic chemicals components: the need for urgent preventive measures. Environmental Sciences Europe, 30, 1-14.

Turning a nuisance into a resource: options and obstacles for sustainable use of beach wrack derived from case studies

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Keywords: Beach wrack, circular economy, coastal protection, soil improvement

ABSTRACT

Beach wrack, consisting of all sort of material washed ashore, is a natural phenomenon occurring on beaches all over the world. Nevertheless, irrespective of being a natural component of beach ecosystems, it has become a specific social problem for local authorities e.g. relating to touristic amenity of the beaches (Hofmann & Banovec 2021). On the other hand, the material offers the chance to become a valuable resource again (Chubarenko et al. 2020).

For sustainable use of the material, a number of obstacles must be overcome. Recently the material gathered by beach management is mostly dumped as biowaste, creating substantial costs for the beach resorts. The problems to be solved range from nature protection aspects via seasonality and composition of material washed ashore to legal regulation issues – all together resulting in a complex mixture of problems which local authorities hardly can deal with alone (Almqvist et al. 2021; Viik 2021). An EU-funded project has tackled these problems in a concerted approach, which results will be presented here.

Starting with a short introduction into the drivers for beach management and the resulting problems, the results of an investigation about technical, legal and economic aspects of recent approaches of inclusion of beach wrack into circular economy schemes are presented. A number of „case studies“ were conducted in the context of an EU-Interreg project (CONTRA). In these case studies, the feasibility of A) use of BW for production of soil improvement products; B) use of BW for production of biochar, C) use of BW for reduction of methane emmission by landfills, D) use of BW for coastal protection, E) use of BW for production of biogas and F) potential of BW for nutrient reduction in coastal Sea areas were tested (Chubarenko et al. 2021). In addition, the experiences with an already established technology for extraction of phycocolloids from BW material will be presented here as well. Aside the well-established use of parts of the material, which can solve the problem just under specific conditions, use for soil improvement product has been shown to be very promising and became transferred to production lines. Biochar-production also showed to offer a large potential, but seems to be limited to low-cost local installations for economical reasons. Use of beach wrack for coastal protection measures as well as for landfill cover also proved to be effective. However, both are single-use options which cannot solve the problem in general. They are options that can and should be applied whenever there is a need for such. The presentation will give an overview about pro and con of all options tested, highlighting the obstacles where further research may provide solutions.

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References:

Almqvist J., Bretz T., Fondahn Å. (2021). Beach wrack in a business environment- Guidance and inspiration towards increased resource utilization based on innovative treatment options. https://www.beachwrack-contra.eu/wp-content/uploads/2021/06/CONTRA-Output04-WEB.pdf

Chubarenko B., Schubert H., Woelfel J. (eds., 2021). Case studies for innovative solutions of beach wrack use. https://www.beachwrack-contra.eu/wp-content/uploads/2021/05/CONTRA-Output05-WEB.pdf

Chubarenko B. Woelfel J., Hofmann J., Aldag S., Beldowski J., Burlakovs J., Garrels T., Gorbunova J., Guizani S., Kupczyk A., Kotwicki L., Domnin D., Gajewska M., Hogland W., Kołecka K., Nielsen J., Schubert H. (2020) Converting beach wrack into a resource as a challenge for the Baltic Sea (an overview). Ocean and Coastal Management, https://doi.org/10.1016/j.ocecoaman.2020.105413

Hofmann J., Banovec M. (2021). Socioeconomic impacts of beach wrack management. https://eucc-d-inline.databases.eucc-d.de/files/documents/00001272_CONTRA-Output02-WEB.pdf

Viik, K. (2021). Identification of national, regional and EU regulations with respect to beach wrack. https://www.beachwrack-contra.eu/wp-content/uploads/2021/05/CONTRA_Legislation_list_Viik_2021.pdf.

Location-Based Resource Analysis Tool for Waste Management and Makers: A Case Study of Pop-Machina

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Keywords: circular city, urban waste flows, pop-machina, urban data analysis

ABSTRACT

Introduction to Urbanisation and Waste

Over the next few decades, the global urban population is expected to experience significant growth. According to the United Nations, by 2045, the number of people living in urban areas will increase to 6 billion, which is 1.5 times higher than today. Such figures suggest that the material consumption by cities will reach 90 billion tonnes by the end of the 2040s (United Nations Environment Programme, 2018). The global proliferation of urbanisation presents a multitude of challenges in addressing the growing demands (World Bank, 2020). As a response, the New Urban Agenda (NUA), announced in 2016 at Habitat III, calls for an urban paradigm shift in planning, finance, development, governance, and city management.

A shift towards better waste management is one of the key aspects of sustainability in urban areas while also crucial in protecting the environment. In the way we currently produce and consume, waste is practically unavoidable. Human waste generation has reached unprecedented levels. Waste in cities has widespread impacts, affecting various aspects such as water quality, flooding, public health, and the perception of public space. Consequently, it is essential to transition from a mindset of waste generation to one of waste minimization and waste reuse (Gutberlet, 2018).

A Shift Towards Circular Economy

By embracing the principles of the circular economy, cities can redefine their production and consumption systems, promoting sustainability. Defined by the Ellen MacArthur Foundation (EMF), circular economy is guided by three key principles: (1) designing out waste from the system, (2) keeping products and materials in use, and (3) regenerating natural systems while focusing on closing resource loops. Additionally, the recovery and restoration of products and materials are facilitated through practices such as reuse, repair, remanufacturing, or recycling (EMF, 2019; Braungart & McDonough, 2002). Material flows in urban areas are highly concentrated due to a multitude of activities, services, and processes taking place in close proximity. Hence, incorporating innovations based on a circular economy at the urban scale is undoubtedly needed if we want to shift towards a global systematic change.

Relationship Between the Maker Movement & Circular Economy

Cities embracing circular economy principles prioritise the reuse of materials and products as a central element of their resource management strategies. According to the Ellen McArthur Foundation (2019), in circular cities waste is minimised through waste-reducing design techniques in building, vehicle, and product assembly. In addition, the focus is on decentralised, on-demand and on-site production. The concept of on-site production is closely connected to the Maker Movement. The Maker Movement is a grassroots innovation originating from communities engaged in DIY activities, aimed at creating or repairing products. The movement revolves around 'collaborative creation' in shared spaces, fostering community-driven innovation that addresses local needs (Seyfang and Smith, 2007). The Maker Movement holds significant potential to foster circularity, especially within local contexts, by presenting alternative manufacturing systems aligned with circular economy principles (Metta & Bachus, 2020). With a strong emphasis on reuse and repair, the movement provides essential technologies, spaces, and knowledge to facilitate these practices (University of Cambridge, 2020; Prendeville et al., 2017). Additionally, the Maker

Movement can contribute to circularity by integrating various waste streams from production and consumption activities throughout the city into their projects.

The H2020 Pop-Machina research focuses on the overlap between the Maker Movement and circular economy approaches. Pop-Machina is a H2020 project funded by the European Union under the research topic of "Demonstrating systemic urban development for circular and regenerative cities". The project's goal is to foster a circular maker movement in urban areas to tackle socio-economic and environmental challenges and reach sustainable development of urban areas (Bachus & Metta, 2020). Pop-Machina aims to reach this goal by supporting and monitoring Circular Maker Communities (CMM) in seven pilot cities including Leuven (Belgium), Thessaloniki and Piraeus (Greece), Kaunas (Lithuania), Venlo (The Netherlands), Santander (Spain), and Istanbul (Turkey). The project focuses on collaborative production for the circular economy with a community approach to understand the ecosystem of maker spaces and contribute to their growth. It is based on three pillars of circularity & sustainability, urban planning, and social inclusion to demonstrate how the maker movement can enable 'redesign of production infrastructure' and what supporting technologies, policies, networks, etc. are needed (University of Cambridge, 2020).

A Location-Based Resource Analysis Tool

This paper introduces a methodology to reach an estimation of waste generated based on the average amount of waste produced by different activities and their spatial distribution around the city. This waste is to be considered as material resources for the maker spaces. Makers can be aided in locating waste as a material resource for local production, and this facilitation can be supported with the design of a digital tool with spatial visualisation of waste production across the city. Following the urban analysis framework of the Pop-Machina project, the tool developed addresses material access and city space in the context of urban spatial information for advanced analysis tools. The aim of the tool methodology is to address the following questions:

- Where is waste generated in the city?
- Who is responsible for the waste generation?
- How much waste is generated with a general estimation?

The method follows a data-driven approach based on available digital models and includes a bibliographic study in order to set up a matrix for waste generation values based on typology and activity. The methodology fits within the micro-scale (1:1000) analysis of Pop-Machina's framework which is at the scale of the neighbourhood to city. OpenStreetMap is used as a resource for base maps and to collect geographical information of different activities around each pilot city.

The methodology for developing the location-based resource analysis tool includes 3 main steps. The first, data collection and classification where the different typologies of waste and waste producers are collected and classified. This is followed by data processing and mapping, whereby the typologies of the activities are mapped in each city. To group the data points, a grid for spatial analysis is set up. The final step is data analysis and visualisation. Through grid-scale maps, waste generation for each part of the city is visualised in terms of typology of waste and for two main sectors of waste producers, namely households and services. These steps will be further elaborated in the following paragraphs.

Data Collection and Classification:

To implement the methodology, two pieces of information are required. The first input, the location and number of activities that produce waste, and the second, the amount of waste and its composition per each activity. For the second input, two datasets are generated, Dataset X and Dataset Y. As there was often a lack of data at the municipal level, data was also collected from international research.

The Dataset X is generated by extracting data points of activities from OpenStreetMap's database, including the locations and amount of activities that produce waste in the city. The research has been focused on both the households and the service sectors. On one hand, the households' data points are collected by counting the number of residential buildings in the city, on the other hand, service sector data points are obtained by identifying the different kinds of activities existing in the city. To create homogeneity among the cities, 250 kinds of activities were grouped into 6 main categories: Office, Education, Restaurant, Hotel, Supermarket, Retail.

Dataset Y follows a bottom-up approach collecting data from the municipal to the international level. The challenge: different waste typologies are studied depending on the geographical contexts and the object of the study. Once again, to create homogeneity, the types of waste were grouped in nine main waste typologies: Organic, Paper, Textile, Plastic, Glass, Metals, E-waste, Wood, and Mix. This phase terminates with a table demonstrating the municipal solid waste compositions per sub-category of services and waste's typology in percentages.

Data Processing and Mapping:

With Dataset X and Dataset Y known, the data processing phase begins with understanding patterns in an area of the city. A strategic grid is created to restructure the data points for analysis. The size of the grid is customised depending on the city. For each cell, a quantification of activities is carried out as well as a total impact score. Using the total impact score, the ratio of contribution of waste generation can then be calculated - the normalisation ratio. Finally, the amount of waste for each cell can be calculated by multiplying the normalisation ratio by the total amount of each waste typology by services or households gathered in the data collection phase.

Data Analysis and Visualisation:

The results of this model visualise wastes' origin and wastes' producer. The final results of the input data are two maps per waste category, one for households and one for the service industry. The resolution of the map's grid can vary based on the level of detail one wishes to obtain. However, to create comparable maps, the scale showing the tonne of waste is maintained for each city.

The methodology has been applied to the seven pilot cities of Pop-Machina research: Leuven (Belgium), Thessaloniki and Piraeus (Greece), Kaunas (Lithuania), Venlo (The Netherlands), Santander (Spain), and Istanbul (Turkey). To demonstrate the implemented methodology, the case study of Leuven was used.

Results & Discussion

The main outcome achieved from the implementation of the methodology is a collection of maps that shows waste's origins and amounts in each city. The visualisations give a friendly and intuitive representation of the collected data and can be useful as a basis for further analysis and discussion on city waste management strategies. The results obtained, even though they are based on input data coming from resources publicly available, are novel and enrich existing information on municipal solid waste and will greatly benefit multiple stakeholders.

These maps provide maker spaces with useful information about materials that can potentially be reused or recycled, as well as infrastructure planning for waste management to shape a new circular flow in the city. For example, if makers have access to this kind of data, "waste" can be maintained within the circular system, eliminating this waste from landfills, and providing a second, third or fourth life. By using the maps, new locations can be identified for maker spaces and FabLabs that can bring makers closer to their materials. Makers will easily be able to identify the kinds of materials in a specific location and create contacts with the producers of this waste. Gaining access to local material considered waste, could also help to reduce costs for the makers.

Not only can it have an impact on makers, it will also impact local authorities. At the municipality or regional level, certain insights can be extrapolated that can then feed into city planning or governmental initiatives. For example, being able to identify the location with the highest amount of waste may prompt local initiatives to encourage recycling or reuse.

Conclusion

In summary, tools, such as the one developed by the POP-MACHINA project, can facilitate the process of keeping materials within the circular economy loop, allowing for resources to be recovered and reused. By mapping data in an understandable and visual way, more people can access and utilise the data which is often difficult to access or not communicated effectively. Encouraging makers to recover and reuse materials becomes much easier with access to data.

Further improvements in the visualisation can be achieved by generating maps for each activity's category should a more detailed analysis per activity be necessary. Future research can be directed to the collection, at municipal level, of actual data regarding the waste's composition per each activity's category. Using this data instead of the ones currently used and collected from scientific papers at international level, would allow a more accurate analysis of waste's origins in the city.

Through research like that of POP-MACHINA, principles of circular economy can be implemented and have an impact on the current waste strategies in our cities. Makers are a key stakeholder, with the creative ability to give new life to materials that would otherwise end up in a landfill. However, they need the information of where and what waste is produced. This paper demonstrates the importance of having access to waste material data to transform the current flows of waste and communicating the data in an effective and coherent manner.

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Map data copyrighted OpenStreetMap contributors and available from https://www.openstreetmap.org.

References:

Braungart, M. and Mcdonough, W. (2002). Cradle to cradle: remaking the way we make things. London Vintage.Circular Economy Action Plan

Ellen MacArthur Foundation (2019). Circular Economy in Cities. [online] . Available at: https://www.ellenmacarthurfoundation.org/assets/downloads/CE-in-Cities-Project-Guide_Mar19.pdf.

EMF (2019). It's called the Circular Economy. https://www.ellenmacarthurfoundation.org/circular-economy/what-is-the-circular-economy

Gershenfeld, N. (2012) *'How to make almost anything: The digital fabrication revolution'*, Foreign Aff., 91, p.43.

Gutberlet, J. (2018) *'Waste in the city: Challenges and opportunities for urban agglomerations'*, Urban Agglomeration [Preprint]. doi:10.5772/intechopen.72047.

Kennedy, C., Cuddihy, J. and Engel-Yan, J. (2007). *The Changing Metabolism of Cities*. Journal of Industrial Ecology, 11(2), pp.43–59.

Metta, J. & Bachus, K., (2020). *Mapping the circular maker movement: from a literature review to a circular maker passport* (Deliverable 2.1). Leuven: Pop-Machina project 821479 – H2020.

Prendeville, S., Hartung, G., Brass, C., Purvis, E. and Hall, A. (2017). Circular Makerspaces: the founder's view. International Journal of Sustainable Engineering, 10(4-5), pp.272–288.

Seyfang, G. and Smith, A. (2007). Grassroots innovations for sustainable development: Towards a new research and policy agenda. Environmental Politics, 16(4), pp.584–603.

United Nations (2017). New urban agenda: H III : Habitat III : Quito 17-20 October 2016. Nairobi: United Nations.

United Nations Environment Programme (2018). The Weight of Cities: Resource Requirements of Future Cities.

https://spaces.oneplanetnetwork.org/system/files/the_weight_of_cities_summary_for_policymakers_may_2019.pdf

University of Cambridge, Department of Architecture (2020). An Integrated Urban Development Framework (Deliverable 2.3) Leuven: Pop-Machina project 821479 – H2020.

World Bank (2020), https://www.worldbank.org/en/topic/urbandevelopment/overview

3D printed Mn-based monoliths for lithium recovery from oilfield brines

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Keywords: produced water, lithium recovery, Mn-based sorbent, 3D printing

ABSTRACT

The oil industry is undergoing a transformational change driven by climate changes and decreasing social acceptance in the last decade. More and more attention is being paid to the management of accompanied waste streams, including formation water. The produced water is difficult to use beneficially due to its complex composition but at the same time its high salinity presents an opportunity. An injection of produced water into discharge wells can be preceded by the recovery of valuable chemical elements, including lithium [Kumar et al., 2019]. The aim of this work is to show the main findings of the Complithium project dedicated to the lithium recovery from oilfield brines in Poland.

Lithium-selective sorbents have been known in the literature for decades but their commercial application is limited by their light and dusty powder form [Baudino et al., 2022]. To overcome this drawback a simple granulation may be applied but the addition of a binder can also result in lower adsorption capacities due to death volumes. Here, in the proposed technology, Mn-based sorbents were prepared using 3D printing method. The ion sieve $LiMnO_2$ was synthesized by a solid state reaction between lithium and manganese salts followed by sintering. The obtained powder was mixed with UV-curable resin at the loading ratio of at least 50 % and printed in the form of cylinders with a cross-section resembling a honeycomb. So prepared sorbents were calcined in air at 450 ^{o}C to partially remove organics and obtain a porous ceramic structure. Such monoliths were activated by 0.1 M HCl and contacted with the real field brine to test sorption kinetics and equilibrium. The crystalline phases of the materials were studied using X-ray diffraction (XRD). The surface morphology of sorbents was analysed by scanning electron microscopy.

Our previous study [Knapik et al., 2023] showed that Mn-based powders allowed the recovery of 99 % of lithium under test conditions and exhibited high selectivity toward Mg, Na, and K. The obtained monoliths keep good sorption properties: lithium recovery can reach as high as >90 % with minimum manganese loss during lithium desorption (<5%). The maximum sorption capacity under optimal pH was 15 mg/g. The pseudo-second-order kinetic equation, which includes the external and internal mass transfer and the chemisorption, fits well to the experimental data. In equilibrium conditions, the relationship between the lithium concentrations in the aqueous phase and the adsorbent was well described by the Langmuir isotherm. The XRD results confirm that the active phase (lithium selective phase) of monoliths was a low crystalline mixture of $LiMnO_2$ and $LiMn_2O_4$. A well-formed macroporous network combined with a high surface area contributed to the high lithium uptake.

The adsorption process may be scale up in fixed-bed (or packed-bed) column systems with the obtained monoliths serving as a specifically designed structured packing. The results proof that 3D printing is a suitable method to fabricate the components required for implementing lithium recovery processes. Lithium recovery from oilfield brines fits well into a closed loop economy i.e. uses waste raw material and the post-process water is re-injected back into the formation.

Acknowledgements

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References:

Kumar, A., Fukuda, H., Hatton, T.A., Lienhard V, J.H., 2019. Lithium Recovery from Oil and Gas Produced Water: A Need for a Growing Energy Industry. ACS Energy Letters 4 (6), 1471–1474, doi.org/10.1021/acsenergylett.9b00779.

Baudino, L., Santos, C., Pirri, C.F., La Mantia, F., Lamberti, A., 2022. Recent Advances in the Lithium Recovery from Water Resources: From Passive to Electrochemical Methods. Advanced Science 9, 2201380, doi.org/10.1002/advs.202201380

Knapik, E., Rotko, G., Marszałek, M., Piotrowski, M., 2023. Comparative Study on Lithium Recovery with Ion-Selective Adsorbents and Extractants: Results of Multi-Stage Screening Test with the Use of Brine Simulated Solutions with Increasing Complexity. Energies, *16* (7), 3149; doi.org/10.3390/en16073149.

Reusing depleted hydrocarbon reservoirs: An ecological alternative?

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Keywords: Reusing, Hydrocarbon reservoirs, Ecology, Carbon capture, Ecological evaluation

ABSTRACT

The paper examines the environmental impacts of the continued use or storage of extracted hydrocarbon reservoirs. The study analyses the global, local, and indirect effects of these activities, including the emission or reduction of carbon dioxide in the atmosphere, the contamination of soil by pollutants, and the prevention of groundwater flow due to geological disturbances. The paper also considers the emissions and pollutants caused by the continued operation of surface facilities.

The results suggest that the closure of the reservoir is the most environmentally friendly option, with the least carbon dioxide and pollution impacts. However, the lack of monitoring of the reservoir is a disadvantage. Two other attractive options are temporary and permanent carbon dioxide storage and geothermal reuse of hydrocarbon reservoirs. However, it is important to note that these options do not provide security against the harmful effects caused by the basic continued operation of the reservoir. Finally, the production of hydrogen from extracted hydrocarbon reservoirs is the most environmentally risky option, as it involves underground techniques that require further research to better assess their impact.

Introduction

The depletion of hydrocarbon reservoirs is a major challenge for the energy industry as traditional extraction methods become increasingly ineffective and uneconomical (Bentley 2002). However, these reservoirs may still have significant value as potential sites for Carbon Capture and Utilization (CCU) and Carbon Capture and Storage (CCS) technologies (Zhang et al. 2022) as well as hydrogen storage (Delshad et al. 2022), which could help reduce greenhouse gas emissions and promote sustainable energy production. In addition, the reuse of depleted reservoirs for closure purposes could help reduce the environmental risks associated with oil and gas production. Moreover, these reservoirs may also offer opportunities for hydrogen production (Massarweh et al. 2023; Bauer et al. 2022) and geothermal applications (Song et al. 2022), further enhancing their potential for sustainable energy production. This paper examines the opportunities and challenges of reusing depleted hydrocarbon reservoirs for CCU and CCS or hydrogen storage, as well as for abandonment (Tveit 2018) and potential use for hydrogen production and geothermal purposes in their ecological aspects.

Methodology

To assess the environmental impacts of reusing depleted hydrocarbon reservoirs, three categories of impact are considered: global, local, and indirect.

As global impacts the emission or reduction of carbon dioxide into the atmosphere and the release of other greenhouse gases as global effects were considered. These effects were evaluated using data on the amount of carbon dioxide and other greenhouse gases released during the development and reuse of hydrocarbon reservoirs.

Local impacts include soil contamination by pollutants, obstruction of groundwater flow by geological alterations, and subsidence and uplift caused by the usage of the depleted geological storage. Additionally, there is the need to evaluate emissions and pollution from surface facilities and their continued operation.

Indirect impacts: Indirect effects resulting from the reuse of hydrocarbon reservoirs have been studied. These include market effects such as the substitution of other technologies for hydrocarbon recovery and the commitment of resources through the use of these processes. The focus was on the implications of these indirect effects for environmental valuation.

A variety of methods were used to assess the impacts of reusing depleted hydrocarbon reservoirs. Literature reviews and simulation modelling were used to assess existing knowledge on the environmental impacts of hydrocarbon recovery and reuse. The literature review provided an assessment of the current state of knowledge on the environmental impacts associated with this practice. In addition, simulation modelling was used to estimate the potential environmental impacts and associated uncertainties resulting from the reuse of depleted hydrocarbon reservoirs.

In conclusion, this study provides a comprehensive assessment of the environmental impacts of the reuse of depleted hydrocarbon reservoirs. By considering global, local and indirect impacts, valuable insights into the environmental implications of this practice have been gained. These findings are of significant importance to policy makers, industry stakeholders and the general public.

Reuse paths and their impact

In order to assess the ecological impact of different use scenarios for depleted hydrocarbon reservoirs, we constructed an impact matrix (Tab. 1), where the severity of the impact was rated on a scale of 0 to 3. Based on this matrix, we found that the environmental impacts of the different use scenarios varied significantly. To better understand these results, we divided the scenarios into global, local, and indirect impacts, and further divided them into smaller impact groups.

Table 7: Environmental impact evaluation of different usage options for depleted oil reservoirs

	Hydrogen production from depleted oil reservoirs	**CCU & CCS & Hydrogen storage**	**Reservoirs closure and abandonment**	**Geothermal usage**
		Global effects		
CO_2 emission	2	2	0	1
Greenhouse gas emission	2	2	0	1
		Local effects		
Soil pollution	2	2	1	2
Groundwater impact	2	2	1	2
Land use	2	2	0	1
Toxic waste production	3	2	0	2
Geomechanically impact	3	2	1	2
		Indirect effects		
Cheaper CO_2 certificates	0	3	0	0
Missing safety monitoring of the old reservoir	0	0	2	1

Results

The main finding of the study is that sealing the reservoir has the best environmental impact in most areas, with the least CO_2 and pollution effects. However, the disadvantage of sealing is the lack of monitoring of the reservoir. Two measures, temporary and permanent carbon dioxide storage and geothermal reuse of oil reservoirs are attractive goals in principle, regardless of feasibility. However, it should be noted that they do not provide security against the harmful effects associated with the continued operation of the reservoir. On the other hand, hydrogen production from depleted oil reservoirs is the most environmentally risky option, as it involves unexplored subsurface methods, and impact assessment and environmental impacts are considered relevant.

Discussion & Conclusion

The above summary provides a qualitative assessment of the environmental impacts of various options for the reuse or storage of produced oil. It is important to note that the data presented in the summary are estimates based on the author's assessment of key factors. Further research and a more detailed examination of the factors are needed for a more precise analysis, especially with regard to indirect and secondary effects and different pollutants.

While the study highlights some potentially attractive options for reusing or storing extracted oil reservoirs, such as temporary and permanent carbon dioxide storage and geothermal reuse, it also points out the limitations and potential risks associated with these measures. For example, the lack of monitoring in sealed reservoirs could lead to unforeseen environmental consequences. Similarly, the hydrogen production option poses significant environmental risks due to the use of untested underground methods and the potential for unknown consequences.

Therefore, while the study provides valuable insights into the environmental impacts of various reuse or storage options for extracted oil reservoirs, it is critical to recognize that the data presented are qualitative and require further investigation. A more in-depth analysis of the various pollutants and their environmental impacts is needed to fully understand the implications of reusing or storing extracted oil reservoirs. Further research and data collection is also needed to assess the indirect and secondary effects of these measures, such as market effects and resource consumption. Only then can we make informed decisions about the best course of action for the environment and our energy needs.

In conclusion, the study provides a comprehensive analysis of the environmental impacts of continued use or storage of hydrocarbon reservoirs and provides valuable insights into potential mitigation measures. Further research could refine the findings and explore more sustainable alternatives to hydrocarbon use.

References:

Bauer, Johannes Fabian; Amro, Moh'd; Alkan, Hakan (2022): Wasserstoffproduktion aus ausgeförderten Kohlenwasserstofflagerstätten: Eine lagerstättentechnische und wirtschaftliche Betrachtung. In: *Geo-energy-systems and subsurface technologies - key elements towards a low carbon world; DGMK/ÖGEW-Frühjahrstagung : Tagungsbericht* 2022, 1, S. 160–180.

Bentley, R. W. (2002): Global oil & gas depletion: an overview. In: *Energy Policy* 30 (3), S. 189–205. DOI: 10.1016/S0301-4215(01)00144-6.

Delshad, Mojdeh; Umurzakov, Yelnur; Sepehrnoori, Kamy; Eichhubl, Peter; Batista Fernandes, Bruno Ramon (2022): Hydrogen Storage Assessment in Depleted Oil Reservoir and Saline Aquifer. In: *Energies* 15 (21), S. 8132. DOI: 10.3390/en15218132.

Massarweh, Osama; Al-khuzaei, Maha; Al-Shafi, Manal; Bicer, Yusuf; Abushaikha, Ahmad S. (2023): Blue hydrogen production from natural gas reservoirs: A review of application and feasibility. In: *Journal of CO2 Utilization* 70, S. 102438. DOI: 10.1016/j.jcou.2023.102438.

Song, Xianzhi; Xu, Fuqiang; Ji, Jiayan; Shi, Yu (2022): Evaluation of the heat extraction performance of an abandoned well pattern in multilayer commingled production oil reservoirs. In: *Natural Gas Industry B* 9 (6), S. 578–587. DOI: 10.1016/j.ngib.2022.11.007.

Tveit, Mari Røstvig (2018): Understanding Leakage Rates in Permanently Abandoned Wells by Studying Natural Hydrocarbon Seepages. University of Stavanger, Norway. Online verfügbar unter https://uis.brage.unit.no/uis-xmlui/handle/11250/2567449.

Zhang, Lingyun; Song, Yanfang; Shi, Jialin; Shen, Qun; Hu, Deng; Gao, Qiang et al. (2022): Frontiers of CO2 Capture and Utilization (CCU) towards Carbon Neutrality. In: *Adv. Atmos. Sci.* 39 (8), S. 1252–1270. DOI: 10.1007/s00376-022-1467-x.

Energy-Efficient Bipolar Membrane Electrodeionization for Integrated Water and Chemical Recoveries from Wastewater of Recycled Polyethylene Terephthalate Processes

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Keywords: water footprint, electrickinetic separation, ion exchange membrane, circular economy, material recovery, cost-benefit analysis

ABSTRACT

Due to long-term recycled content objectives everywhere in the globe, the demand for recycled polyethylene terephthalate (rPET) is anticipated to rise. However, the lye washing procedure used in the production of rPET uses more fresh water. In this study, we incorporated bipolar membrane electrodeionization (BMEDI) for on-site regeneration of clean water as well as the acid and base to circular to achieve low environmental effect. We first conduct treatment tests on the real rPET effluent. We meticulously assessed performance of water reclamation and acid/ base production, current efficiency, power consumption as well as productivity. The findings showed that, despite BMEDI's higher energy costs for water reclamation, 63.5±8.8% of SO_4^{-2} and 75.8±7.32% of Na^+ could be recovered from the wastewater and reuse as sulfuric acid and sodium hydroxide solution, respectively. The economic analysis demonstrates that using BMEDI in the rPET process is more cost-effective than using an existing technique like reverse osmosis. The water footprint was also ~96% reduced. In conclusion, by recovering water and chemicals to attaining zero liquid discharge, the integration of BMEDI proven to be technically possible and economically viable for reducing the environmental impact of rPET products.

1. Introduction

Recycled polyethylene terephthalate (rPET) bottles require more water to produce than PET bottles made from fossil fuels [1, 2]. To ensure cost-effective operations and reduce any negative environmental effects, closed loop water cycles must be put in place. By cleaning tainted plastic on the washing line, the washing line plays a significant part in the recycling of plastic, necessitating the use of washwater. According to previous studies, 1 kilogram of rPET requires about 3 kg of water to create, mostly during the washing process [1]. Reverse osmosis (RO), flocculation, coagulation, filtering, adsorption, and other technologies have all been suggested for the rPET business to reclaim wastewater. These conventional methods, however, have problems like high energy use, secondary brine contamination, and the need of additional chemicals. Additionally, the chemical compounds added during the PET reprocessing process help the washing wastewater's electrical conductivity. Sulfuric acid and sodium hydroxide are two of these chemical substances that produce a lot of greenhouse gases. Therefore, it is imperative to create a separation method that is both environmentally beneficial and energy-efficient in order to recycle plastic washwater and encourage responsible resource usage.

An even more tempting approach to this problem is electrodeionization with bipolar membrane (BMEDI), which may split water to produce protons and hydroxide ions, converting salt-containing wastewater into acid and basic components [3]. For boron removal and chemical recovery, Chaudhury et al. integrated

BMEDI into a sea water desalination process [4]. By converting Na_2SO_4 to NaOH and H_2SO_4 for reusing, Lior Monat et al. [5] showed that BMEDI is a practical method for affordable and sustainable phosphogypsum processing. However, there hasn't been much research on the use of BMEDI for treating brackish wastewater, which has a conductivity range typically between 1 and 10 g/L.

BMEDI adoption and viability on an industrial scale are currently constrained by technological and financial limitations, as well as a dearth of subject matter expertise. To assess the viability of our strategy, we methodically looked into variables including acid and base production, electricity usage, and current efficiency. Based on these results, we did a thorough evaluation and comparison of the preliminary cost-benefit analysis of incorporating BMEDI into the rPET process in comparison to the widely utilized RO and electrodialysis (ED) traditional procedures. Last but not least, a preliminary economic analysis was performed along with a water footprint calculation for each rPET bottle design procedure. These calculations were performed to learn more about the viability of massive activities.

2. Methods and Materials

2.1 Wastewater

In this study, the real wastewater collected and from the wastewater treatment plant of a plastic recycling (rPET) process in Taiwan was used.

Table 1. Composition of washing wastewater and effluent from the rPET company in Taiwan.

Parameter	Unit	Effluent
Temperature	℃	23.9 ± 1.4
pH	-	7.88 ± 0.06
EC	µS/cm	6257 ± 742
COD	mg/L	96 ±107
SS	mg/L	10.6 ± 7.0
Na^+	mg/L	1587 ± 132
SO_4^{-2}	mg/L	3215 ± 98
Cl^-	mg/L	257 ± 123

2.2 Electrodeionization with bipolar membrane (BMEDI)

BMEDI comprises of electrodes, anion exchange membranes, cation exchange membranes, and bipolar membranes. Ion exchange membranes are used as a means of separating the various compartments inside the stack, as depicted in Figure 1. The ions in the feed solution go through the membranes to be separated and concentrated into the relevant compartments as the feed solution flows into the dilute chamber. In the meantime, water silting that takes place at the surface of bipolar membranes results in the production of hydrogen ions and hydroxide ions. Thus, throughout the separation process, acidic and basic solutions would be produced.

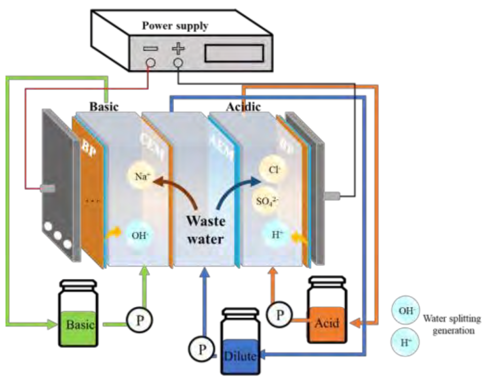

Figure 1. Experimental schematic diagram of BMEDI stack configuration.

2.3 Performance Evaluation

We methodically investigated the performance of conductivity removal ratio, acid and base production, current efficiency, electricity consumption, and productivity.

2.4 Determination of Process Water Footprint

To understand the water impact and inform decision-making towards sustainable water management, water footprint (WF) is assessed to provide a comprehensive assessment of water usage, including both the water consumed and the water polluted or degraded during the process. In this study, the WF is defined as the volume of fresh water used directly and indirectly to produce per unit product or in a process (m^3/ton or kg/liter). WF considers three components that is green, blue and grey water footprints, as described by following equation:

$$WF = WF\ green + WF\ blue + WF\ grey$$

3. Results and discussion

3.1 Performance evaluation of water reclamation and chemical recovery

This study demonstrated treatment testing of the real effluent from the rPET process using BMEDI and to meet with the water quality standard that calls for conductivity below 1 mS/cm for water reuse in order to reduce water footprint. Within the first 30 minutes of desalination, BMED achieved an ion removal ratio of 80% with an outflow concentration < 1000 mg/L. Even while current efficiency is greater than 80% in the first 30 minutes, the lack of leftover ions and the water splitting reaction caused it to rapidly fall after that. Additionally, it was discussed how various operating conditions affected performance metrics. According to the results, operating conditions with an applied voltage of 12.5, a concentrated volume of 625 mL, and a productivity of 27.5 L/m^2/h produce higher performance, with the energy consumption of 9.0 kWh/m^3 and output of 27.5 L/m^2/h. In the meantime, high purity 30.9 mM H_2SO_4 and 95.5 mM NaOH were produced and could be recycled for the PET regeneration process.

3.2 Economic analysis

The production of the acid and base solutions by BMEDI needed excessive amounts of fresh water, however one of these solutions can be utilized again in the washing process and the other can be used as a by-product or in the flotation process. According to the experimental results, BMED can recover 76% of Na and produce a 79 mM NaOH solution at 12.5 V. This base solution can be used again after cleaning and before adding caustic soda. Additionally, 58% of SO_4 was recovered as a 31 mM sulfuric acid solution, which could be used again in wastewater treatment or the floating procedure that needed H_2SO_4 and fresh water to remove contaminants from small PET pieces. The cost of acid chemicals can be reduced by around one-sixth as a result. Additionally, the extra acid can be sold to another industry or used for other purposes within the factory, which will further reduce costs. Even though BMEDI uses more energy, the cost of electricity can be offset by lowering the costs of chemicals, water, and sewage by 47%, 38%, and 100%, respectively. Overall, operating costs were decreased by 11% and 7%, respectively, when compared to the baseline and business as usual situations. However, it should be noted that in this case, the cost of energy and the membrane accounts for more than 50% of the overall running cost since the bipolar membrane, which is 5 times more expensive than A/CEM, has a greater cost and higher electricity resistance. Therefore, for the development of BMEDI systems, lowering the cost of the bipolar membrane, increasing process efficiency, and minimizing energy usage are crucial.18 However, scenario 4 is the most cost-effective way and uses less material to regenerate PET from bottles. This demonstrates the effectiveness of BMEDI as a method for closing the water loop, attaining zero liquid discharge, and implementing green chemistry.

3.3 Water footprint analysis

To evaluate water usage and the effects on the environment, the WF, including blue and grey WFs, was examined. A ton of rPET required 3100 kg of fresh water to generate under the baseline scenario. About 3.1 m^3 per tonne is the blue WF. 3.1 m^3 of effluent with a conductivity of ~6260 S/cm would be produced by one tonne of rPET, assuming there is no water loss throughout the water treatment process. 17.7 m^3 are in the grey WF. Approximately 65% of the water used for washing was cleaned up using conventional water reuse treatment techniques like brine from RO and ED. As a result, the amount of water used per tonne of rPET was decreased to about 2.5 L. However, the scenario's effluent was considered when calculating the grey WF. Around 80% of conductivity would be recovered by ED or RO from diluted compartments to concentrated compartments. Under normal operating conditions, at a volume ratio of 1.00: 0.54, approximately 1.16 m^3 of wastewater with a conductivity of 18 mS/cm for one tonne of rPET is produced, yielding a grey water fraction of ~20.3 m^3 per ton. It is important to note that in traditional treatment methods, the grey WF is typically higher than the blue WF, indicating the significance of ion recovery processes. BMED has the lowest WF, 1.94 m^3/tonne, for instance. Since BMED does not discharge any liquids, it has no impact on grey water. In conclusion, BMED could improve resistance to freshwater scarcity and reducing water footprints by 96% when compared to the other scenarios.

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References

[1] P. T. Benavides, J. B. Dunn, J. Han, M. Biddy, and J. Markham, "Exploring Comparative Energy and Environmental Benefits of Virgin, Recycled, and Bio-Derived PET Bottles," *ACS Sustainable Chemistry & Engineering,* vol. 6, no. 8, pp. 9725-9733, 2018, doi: 10.1021/acssuschemeng.8b00750.

[2] L. Shen, E. Nieuwlaar, E. Worrell, and M. K. Patel, "Life cycle energy and GHG emissions of PET recycling: change-oriented effects," *International Journal of Life Cycle Assessment,* vol. 16, no. 6, pp. 522-536, Jul 2011, doi: 10.1007/s11367-011-0296-4.

[3] Y. Zhao, H. Wang, C. X. Jiang, L. Wu, and T. W. Xu, "Electrodialysis with notched ion exchange membranes: Experimental investigations and computational fluid dynamics simulations," *Sep. Purif. Technol.,* vol. 130, pp. 102-111, Jun 2014, doi: 10.1016/j.seppur.2014.04.010.

[4] S. Chaudhury, N. Harlev, O. Haim, O. Lahav, and O. Nir, "Decreasing Seawater Desalination Footprint by Integrating Bipolar-Membrane Electrodialysis in a Single-Pass Reverse Osmosis Scheme," *Acs Sustainable Chemistry & Engineering,* vol. 9, no. 48, pp. 16232-16240, Dec 2021, doi: 10.1021/acssuschemeng.1c05504.

[5] L. Monat, S. Chaudhury, and O. Nir, "Enhancing the Sustainability of Phosphogypsum Recycling by Integrating Electrodialysis with Bipolar Membranes," *Acs Sustainable Chemistry & Engineering,* vol. 8, no. 6, pp. 2490-2497, Feb 2020, doi: 10.1021/acssuschemeng.9b07038.

Session B2: Green roofs and walls

If you build it, they will come: invertebrates on green roofs

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Keywords: urban ecology, invertebrate ecology, immigration ecology, green infrastructure

ABSTRACT

Since the industrial revolution, urban expansion has leapt forward and shows no sign of slowing (Horák et al., 2022; Shafique et al., 2018; Wang et al., 2022). This development has led to extensive loss and fracturing of habitat (Cameron et al., 2012; Horák et al., 2022; Parker & Zingoni de Baro, 2019). Retention of remnant vegetation is known to support functional urban ecosystems (Kabisch et al., 2017), therefore, the creation of new green spaces in cities could better support urban biodiversity (Cameron et al., 2012; Kabisch et al., 2017; Mathey et al., 2015; Parker & Zingoni de Baro, 2019). In addition to the ecological benefits that this brings, urban greenery has been seen to improve the mental and physical health of urban residents (Burley, 2018; Kabisch et al., 2017; Suppakittpaisarn et al., 2017; Tzoulas et al., 2007), but also provide community areas for recreation and exercise (Jim & Chen, 2006; Shafique et al., 2018).

Where ground-level space is unavailable or costly, green roofs can provide a unique solution to introducing greenery into urban areas (Cameron et al., 2012; Horák et al., 2022). While the concept of growing plants on roofs has a long history, the modern practice of installing green roofs has existed for less than 100 years (Wang et al., 2022). Here 'green roof' is used as a broad definition encompassing all forms of elevated vegetation built on the roofs of residential, industrial, or administrative buildings. Within the world of green roofs, they can be categorized many ways, such as by substrate depth, vegetation composition, or intended purpose (Chell et al., 2022; Dusza et al., 2020; Jacobs et al., 2022; Rumble et al., 2018; Schrader & Böning, 2006).

Green roofs as ecosystems have received little emphasis in the literature, as most research is focused on the design and construction aspects of green roofs (Dvorak & Volder, 2010; Scolaro & Ghisi, 2022; Shuraik et al., 2022). Other ecosystem contexts such as arid and tropical climates, and the paucity of research available, present an exciting prospect for developing a deeper understanding of how these built green environments can support urban biodiversity, and in particular invertebrates. A diverse array of invertebrates could provide myriad ecosystem services to green roofs (Braaker et al., 2017; Fabián et al., 2021; Gonsalves et al., 2022; Mathey et al., 2015; Shafique et al., 2018). Detritivore invertebrates like earthworms and beetles can catalyse soil nutrient cycles, increasing soil quality and subsequently plant health (Ganault et al., 2022; Santonja et al., 2018). Nectivorous and pollinator invertebrates like bees and butterflies can promote flower blooming and increase aesthetic value of a space (Katumo et al., 2022). Predatory invertebrates such as spiders and ladybeetles can control the populations of pest species (Fabián et al., 2021). In addition, these invertebrate communities can also form part of higher order ecological food chains, in particular insectivorous birds and microbats (Partridge & Clark, 2018).

The lack of green roof specific research in urban invertebrate ecology is a gap in the literature, and it is important to know exactly where the major gaps are before further investigation can take place.

Therefore, we completed a systematic quantitative literature review (SQLR) to identify these gaps, while simultaneously highlighting patterns and common findings in the current research.

Method

The method for this SQLR included the following search syntax: “('Green Roof*' OR 'Roof* Garden*' OR 'Sky Garden*') AND (‘Ecology’ OR ‘Invertebrate*’ OR ‘Arthropod*’ OR ‘Insect*’)”. This syntax was used to search the databases Scopus, Web of Science, and Greenfile. A total of 362 unique experimental articles were found, while were reduced to 34 after title, abstract, and full text screenings to articles specifically focussed on invertebrate ecology. Each of the final articles were analysed thoroughly for bibliographic data, location of experiments, experimental methods, and major findings including those related to building and roof design, immigration barriers, ecological drivers, and taxonomic makeup.

Key results

Articles were predominantly (~76%) of the studies were from temperate climates (as defined by Koppen Climate classification) with the majority from Western Europe or North-East of the United States of America. Continental climates (~21%) studies, and one study (~3%) took place in a tropical climate.

Control selection and sampling method varied, but the most common were comparison between green roofs and conventional roofs (~47% of studies), and pitfall and pan traps (~56% of studies).

There were three common findings across the literature:

1. **Green roofs are restricted from immigration by low mobility, species from nearby ground areas.** Related to this finding was the more frequent observation of substrate-nesting bees on green roofs compared to the ground. In addition, many studies reported that some species found on green roofs were not found at ground level.
2. **The higher diversity of plants installed on green roofs correlated with higher diversity of invertebrates.**
3. **Increased area and heterogeneity of green roof design correlated with increased invertebrate diversity.**

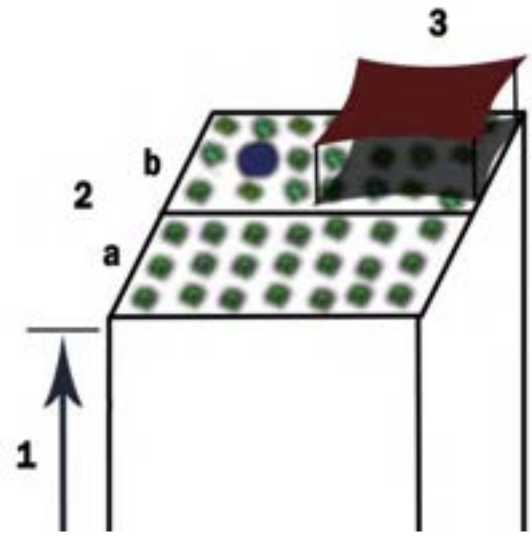

Figure 15 Examples of two green roofs (a and b) showing the main findings of the articles reviewed. 1. That green roofs are restricted from immigration by low mobility species from nearby ground areas. 2. That increased diversity of plants installed on green roofs correlated with higher diversity of invertebrates. And 3. That increased area and heterogeneity of green roof design correlated with increased invertebrate diversity. In this case, roof a. would be presumed to have a lower level of invertebrate diversity compared to roof b, which has a wider variety of plants, and examples of heterogeneous design such as a small pond and shade cloth.

Discussion

Green roofs are more costly than conventional, unvegetated roofs. This cost is the most likely reason that most of the research into invertebrate ecology on green roofs is concentrated in the wealthier parts of Europe and North America. Invertebrate populations on green roofs in arid, monsoonal, rainforest, and even subarctic regions have not been significantly reported on. It is likely that these populations, especially in monsoonal areas, will have vastly different ecosystems from those in more moderate climates (Wang et al., 2017).

Immigration restriction

The restriction of immigration paths to green roofs from ground areas for invertebrates is one of the most common findings throughout the literature reviewed (Braaker et al., 2014; Dromgold et al., 2020; Gonsalves et al., 2022; Jacobs et al., 2022; Kyrö et al., 2018; MacIvor & Lundholm, 2011; Madre et al., 2013; Tonietto et al., 2011). Advantaging more mobile invertebrates can lead to vastly different population ratios on roofs compared to the ground. The primary factor in this barrier being the elevation, but another being the lack of vegetation on the walls that an invertebrate must scale. While the latter could be altered with green walls or garden beds that act like steppingstones, this may not entirely erase the effect of the elevation (Tonietto et al. 2011). This effect being primarily the formation of less diverse assemblages of invertebrates on those green roofs (Dromgold et al. 2020, Fabián et al. 2021, Lin & Chen 2022, and Wooster et al. 2022).

One interesting effect of this barrier was observed by Braaker et al. (2017), Passaseo et al. (2020), and Tonietto et al. (2011). These three articles found substrate-nesting bees to be present at a greater proportion on green roofs than on the ground level. The more well-known cavity-nesting bees were found at similar levels on green roofs as compared to the ground. Substrate-nesting bees are just as mobile at their cavity-nesting cousins and can quickly surmount the elevational barrier provided by green roofs. This allows them to quickly establish a foothold in that green roof habitat, compared to less-mobile substrate-nesting species, which struggle to scale the walls. There are most likely many other population differences on green roofs compared to the ground that were unable to be identified by these papers.

The presence of invertebrate species on roofs that are not present on the ground prompts the question of how they arrived there if not from the ground. There is the possibility that they could have arrived during the construction process, either in soil or attached to the plants themselves. While some of these may be advantageous, like earthworms which provide direct benefits to the soil (Jusselme et al., 2019), there is the possibility of this importing invertebrates from drastically different ecosystems that could be considered pests or invasive species.

Horizontal migration may be another explanation for the presence of species on green roofs while being absent from the ground level ecosystems. This horizontal migration could be caused by building-to-building travel, or by wind dispersal. Wind dispersal consists of light invertebrates being swept up with the wind and deposited sometimes kilometers away, this is observed regularly in spiders (Joimel et al., 2018; Joimel et al., 2022).

The building-to-building travel is exclusive to taxa of invertebrates that can fly under their own power such as flies. Many papers found that a higher density of green roofs resulted in more similar assemblages of invertebrates (Braaker et al., 2014; Fabián et al., 2021; Joimel et al., 2018). This movement and similarity is similar to Island Biogeography Theory, with each building mimicking an island in an archipelago. This theory is an extensive pre-existing field and has been applied to urban habitat fragmentation in the past (Losos et al., 2010; MacArthur & Wilson, 1967; Whittaker & Fernandez-Palacios, 2006). By incorporating an increased density of green roofs into city planning, we can increase the connectivity of these novel habitats, allowing for more robust ecosystems.

Spatial Heterogeneity

Increased structural heterogeneity was found to increase invertebrate diversity along various axes (Braaker et al., 2017; Fabián et al., 2021; Gonsalves et al., 2022; Jacobs et al., 2022; Nash et al., 2016; Rumble et al., 2018). These structural differences, including vegetational differences, allows a wide array of ecological niches which can be exploited by invertebrates. One aspect of vegetational diversity was underrepresented. There was only one article found (Wang et al. 2013) that discussed how trees may affect invertebrate assemblages. The different degrees to which these various axes of heterogeneity can be manipulated to increase biodiversity of invertebrates is an interesting prospect for research.

As noted previously, robust invertebrate populations on green roofs can provide many ecosystems services. While there is a general paucity of research here, there was note of leaf litter breakdown potential and nutrient cycling by Jusselme et al. (2019). While the catalytic effect of invertebrates in this process is quote well-researched in non-urban environments, the effect on urban environments like green roofs is underdeveloped (Ganault et al., 2022; Santonja et al., 2018). With respect to decrease in pest species, Wong & Jim (2016) noted that green roofs had far less mosquitos sampled on green roofs compared to ground and conventional roof environments. While these two examples are relatively new, they show that there may be more unknown services that healthy assemblages of invertebrates can provide for green roofs and urban areas.

Summary

By understanding more about green roofs and the ecosystems of invertebrates that occupy them, we can improve design processes by incorporating the major benefits of those ecosystems. There is still much to understand green roofs, including how some possess species not found at nearby ground levels. Furthermore, the effects of arid, tropical, and subarctic climates are under-researched compared to more temperate climates.

While there is relatively little research into the field so far, the semi-isolated nature of green roofs makes them a novel environment to study. The main summations being brough forward here include the restriction of immigration by low mobility invertebrates onto green roofs, and that this may be significant impacts on the species makeup of green roofs. While green roofs generally have lower invertebrate diversity than ground environments, this can be to an extent countered through heterogeneity in design. This includes vegetation, which has the greatest effect on diversity of invertebrates. More diverse and developed invertebrate populations can provide many services to those ecosystems, such as increasing soil health and decreasing pest levels.

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References:

Braaker, S., Ghazoul, J., Obrist, M. K., & Moretti, M. (2014). Habitat connectivity shapes urban arthropod communities: the key role of green roofs [Article]. Ecology, 95(4), 1010-1021. https://doi.org/10.1890/13-0705.1

Braaker, S., Obrist, M. K., Ghazoul, J., Moretti, M., & Cuddington, K. (2017). Habitat connectivity and local conditions shape taxonomic and functional diversity of arthropods on green roofs [Article]. Journal of Animal Ecology, 86(3), 521-531. https://doi.org/10.1111/1365-2656.12648

Dromgold, J. R., Threlfall, C. G., Norton, B. A., & Williams, N. S. G. (2020). Green roof and ground-level invertebrate communities are similar and are driven by building height and landscape context [Article]. Journal of Urban Ecology, 6(1), Article juz024. https://doi.org/10.1093/jue/juz024

Dusza, Y., Kraepiel, Y., Abbadie, L., Barot, S., Carmignac, D., Dajoz, I., Gendreau, E., Lata, J. C., Meriguet, J., Motard, E., & Raynaud, X. (2020). Plant-pollinator interactions on green roofs are mediated by substrate characteristics and plant community composition [Article]. Acta Oecologica, 105, Article 103559. https://doi.org/10.1016/j.actao.2020.103559

Fabián, D., González, E., Sánchez Domínguez, M. V., Salvo, A., & Fenoglio, M. S. (2021). Towards the design of biodiverse green roofs in Argentina: Assessing key elements for different functional groups of arthropods [Article]. Urban Forestry & Urban Greening, 61, N.PAG-N.PAG. https://doi.org/10.1016/j.ufug.2021.127107

Ganault, P., Barantal, S., Coq, S., Hättenschwiler, S., Lucas, S., Decaëns, T., & Nahmani, J. (2022). Leaf litter morphological traits, invertebrate body mass and phylogenetic affiliation explain the feeding and feces properties of saprophagous macroarthropods. European Journal of Soil Biology, 109, 103383. https://doi.org/https://doi.org/10.1016/j.ejsobi.2021.103383

Gonsalves, S., Starry, O., Szallies, A., & Brenneisen, S. (2022). The effect of urban green roof design on beetle biodiversity [Article]. Urban ecosystems, 25(1), 205-219. https://doi.org/10.1007/s11252-021-01145-z

Jacobs, J., Berg, M., Beenaerts, N., & Artois, T. (2022). Biodiversity of collembola on green roofs: A case study of three cities in Belgium [Article]. Ecological Engineering, 177, Article 106572. https://doi.org/10.1016/j.ecoleng.2022.106572

Joimel, S., Grard, B., Auclerc, A., Hedde, M., Le Doaré, N., Salmon, S., & Chenu, C. (2018). Are Collembola “flying” onto green roofs? [Article]. Ecological Engineering, 111, 117-124. https://doi.org/10.1016/j.ecoleng.2017.12.002

Joimel, S., Grard, B., Chenu, C., Cheval, P., Mondy, S., Lelièvre, M., Auclerc, A., & Vieublé Gonod, L. (2022). One green roof type, one Technosol, one ecological community [Article]. Ecological Engineering, 175, Article 106475. https://doi.org/10.1016/j.ecoleng.2021.106475

Jusselme, M. D., Pruvost, C., Motard, E., Giusti-Miller, S., Frechault, S., Alphonse, V., Balland-Bolou-Bi, C., Dajoz, I., & Mora, P. (2019). Increasing the ability of a green roof to provide ecosystem services by adding organic matter and earthworms [Article]. Applied Soil Ecology, 143, 61-69. https://doi.org/10.1016/j.apsoil.2019.05.028

Pickering, C., & Byrne, J. (2014). The benefits of publishing systematic quantitative literature reviews for PhD candidates and other early-career researchers. Higher Education Research & Development, 33(3), 534-548. https://doi.org/10.1080/07294360.2013.841651

Rumble, H., Finch, P., & Gange, A. C. (2018). Green roof soil organisms: Anthropogenic assemblages or natural communities? [Article]. Applied Soil Ecology, 126, 11-20. https://doi.org/10.1016/j.apsoil.2018.01.010

Sánchez Domínguez, M. V., González, E., Fabián, D., Salvo, A., & Fenoglio, M. S. (2020). Arthropod diversity and ecological processes on green roofs in a semi-rural area of Argentina: Similarity to neighbor ground habitats and landscape effects [Article]. Landscape and Urban Planning, 199, Article 103816. https://doi.org/10.1016/j.landurbplan.2020.103816

Santonja, M., Pellan, L., & Piscart, C. (2018). Macroinvertebrate identity mediates the effects of litter quality and microbial conditioning on leaf litter recycling in temperate streams. Ecology and evolution, 8(5), 2542-2553. https://doi.org/10.1002/ece3.3790

Schrader, S., & Böning, M. (2006). Soil formation on green roofs and its contribution to urban biodiversity with emphasis on Collembolans [Article]. Pedobiologia, 50(4), 347-356. https://doi.org/10.1016/j.pedobi.2006.06.003

Tonietto, R., Fant, J., Ascher, J., Ellis, K., & Larkin, D. (2011). A comparison of bee communities of Chicago green roofs, parks and prairies [Article]. Landscape and Urban Planning, 103(1), 102-108. https://doi.org/10.1016/j.landurbplan.2011.07.004

Wang, J. W., Poh, C. H., Tan, C. Y. T., Lee, V. N., Jain, A., & Webb, E. L. (2017). Building biodiversity: drivers of bird and butterfly diversity on tropical urban roof gardens [Article]. Ecosphere, 8(9), 1-N.PAG. https://doi.org/10.1002/ecs2.1905

Wang, L., Wang, H., Wang, Y., Che, Y., Ge, Z., & Mao, L. (2022). The relationship between green roofs and urban biodiversity: a systematic review. Biodiversity and Conservation, 31(7), 1771-1796. https://doi.org/10.1007/s10531-022-02436-3

Whittaker, R. J., & Fernandez-Palacios, J. M. (2006). Island Biogeography : Ecology, Evolution, and Conservation. Oxford University Press, UK. https://public.ebookcentral.proquest.com/choice/publicfullrecord.aspx?p=415455

Wong, G. K. L., & Jim, C. Y. (2016). Do vegetated rooftops attract more mosquitoes? Monitoring disease vector abundance on urban green roofs [Article]. Science of the Total Environment, 573, 222-232. https://doi.org/10.1016/j.scitotenv.2016.08.102

Wooster, E. I. F., Fleck, R., Torpy, F., Ramp, D., & Irga, P. J. (2022). Urban green roofs promote metropolitan biodiversity: A comparative case study [Article]. Building & Environment, 207, N.PAG-N.PAG. https://doi.org/10.1016/j.buildenv.2021.108458

Proposing a holistic experimental setup for green roof flammability testing

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Keywords: Green roof flammability, Fire safety, Vegetated roofs, Flammability testing

ABSTRACT

Green roofs are increasingly incorporated into cities worldwide due to their key role in solving urban problems like mitigating heat islands, facilitating ecology, improving mental health, and controlling stormwater. The implementation of green roofs can be hindered by the perceived fire risk and short experience with green roofs in some countries such as Australia (Abuseif et al., 2022). As plant flammability classifications are not standardized internationally, it is difficult to make comparisons for fire safety purposes during species selection (Murray et al., 2020). Particularly in Australia, intense bushfires have policymakers, landscape architects, and fire and rescue services questioning the safety of green roofs, as they transfer perceptions and experiences of wildland-urban interface fires to engineered soil-plant systems (Chell & Michael, 2023). Green roofs, however, are intrinsically distinct from natural ecosystems because of the intentional engineering that underpins the design of soils, plant communities, and maintenance regimes. The fear of fire and perception of fire risk is particularly directed towards Australian native plants, with some professionals calling for the exclusive use of exotic species or native rainforest species (Chell & Michael, 2023). This potential exclusion of a large range of native plants for green infrastructure applications would have negative impacts on the ecological restoration capacity and sense-of place that green roofs can achieve when greening our cities. It is therefore crucial that key flammability characteristics are derived to provide evidence for risk-based decision making. Fire researchers are calling for more plant flammability testing (Murray et al., 2020) to aid in the consultation of plant-selection and fire safety assessments of vegetated systems. Yet, there is very limited knowledge available on green roofs, and for the limited information available, most efforts have been focused on individual components like substrates (Gerzhova et al., 2020). Sound scientific evidence is needed to assess the flammability risk of green roofs considering them as a whole system inclusive of the plant community, green roof media/substrate, and underlay fabrics. Whole-plant flammability is linked to fuel conditions such as moisture content in the foliage and plant biomass (Etlinger & Beall, 2005) as the heat release rate of a given species is a function of its moisture content (Weise et al., 2005). Another flammability parameter influenced by moisture content is ignition time. For example, dead (detached) *Eucalyptus saligna* leaves ignited eight times faster than live leaves with a higher moisture content (Ramadhan et al., 2021). Other key plant characteristics that influence flammability are height, leaf energy content (Long et al., 2006), leaf length and width and (specific) leaf area, bound oils within leaves / volatile compounds (Murray et al., 2013), and leaf-dry matter content, making leaf functional traits a core property influencing plant flammability (Alam et al., 2019). Secondary attributes that influence fire behaviour of plant communities are plant bulk density, ember production, volume of leaf litter produced, and (in the case of trees) the presence of decorticating bark (Murray et al., 2020). To get a more holistic understanding of the flammability risk of vegetated systems, intrinsic attributes used to describe the flammability of vegetation like ignitability, sustainability and combustibility need to be assessed together. *Ignitability*, defined as time until ignition after exposure to a heat source can be quantified by the variables of ignition time, critical temperature, and critical heat flux. *Sustainability*, defined as the ability to sustain combustion once ignited, can be quantified by inspecting the duration of visual flaming, duration of elevated temperatures, duration of heat release, area or volume consumed, or the total heat released. *Combustibility*, defined as rapidity of combustion after ignition can be measured by visual flame spread rate or height, rate of temperature increase, rate of heat release, peak temperature and its time, and peak heat release rate and its time

(White & Zipperer, 2010). Currently there is no accepted experimental method for determining green roof flammability characteristics as a whole, coherent system. This study therefore aims to develop an experimental setup that will enable green roof flammability parameters to be derived at an appropriate scale to meaningfully inform fire risk and strategic decision making during the green roof design process and plant selection. Green roof modules were developed that reflect all interacting green roof components during fire testing.

Methods

Stainless steel modules of 1.22m x 0.5m size were manufactured and filled with a locally sourced, mineral-based green roof substrate. The green roof modules were then planted with 12 individuals of the Australian native groundcover species *Scaevola albida* (pale fan-flower, Figure 1, inset). The plants were grown in-situ on an exposed roof at Griffith University Nathan campus to simulate natural green roof growing conditions. After plant establishment, the modules were subjected to different levels of water stress by moving them into a glasshouse environment where they were sheltered from receiving water until the plants were water stressed to warrant fire safety concerns. Subsequently, the modules were transported for testing in the fire laboratory at the University of Queensland, where the initial system state was determined. Green coverage of the canopy was determined from image analysis of above head photographs of the module using standard methods (Chell et al., 2022) and soil moisture was measured using a calibrated soil moisture probe (5TM, Campbell Scientific) in conjunction with a handheld reader (ProCheck, METER Group) right before the start of the fire experiment. A customizable number of sensors, substrate types and different plant species or water-retention / drainage materials can be employed to investigate potential design parameters and their combinations (Figure 16).

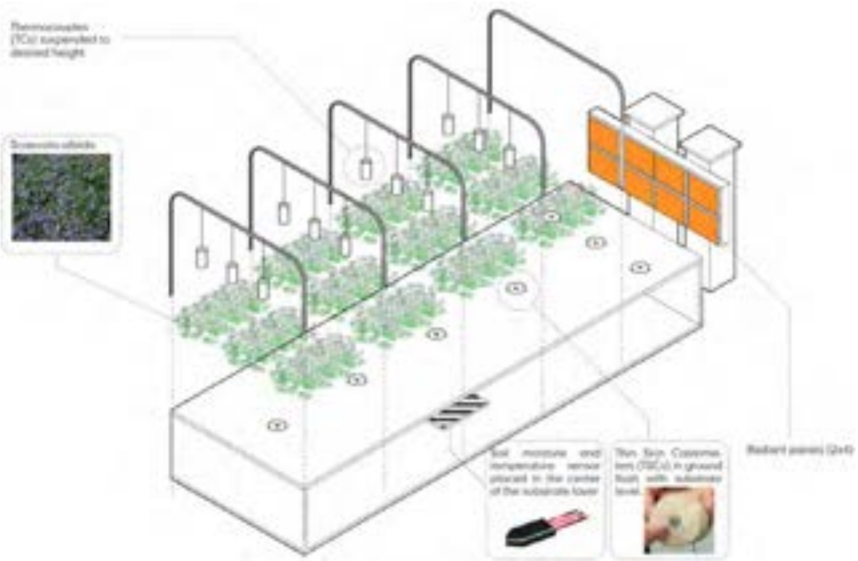

Figure 16 Exploded axonometric diagram of the experimental setup (green roof modules with sensing (TC: Thermocouple, TSC: Thin skin calorimeter))

Fitted sensors during heat exposure included thermocouples (TCs, 1.5 mm sheathed, K-type) that were suspended within the foliage at different distances from the heat source to track temperatures of the gas phase. Thin skin calorimeters (made using instructions by Hidalgo et al. (2017)) were fitted flush to substrate level to record heat flux to the substrate at the same distances from the heat source as the TCs (Figure 16). Sensor cables were protected from melting using tin foil wrapping. To measure time to ignition (delay), rate of flame spread, and flame height, a video camera was deployed perpendicular to the modules side to record visual flaming characteristics against a black background using distance markings on the green roof module's side (Figure 17). The experimental setup quantifies flammability characteristics (ignitability, combustibility, and sustainability) by investigating a green roof module exposed to gas fuelled radiant panels (Radimax, Gogas) underneath a large-scale extractor hood fitted with a gas analyser to measure the heat release rate (HRR). To validate the feasibility of the experimental setup, an exploratory test series was run at a heat exposure of 50 kW/m^2 at the front of the module. Radiant panel location to provide the target heat was determined by a distance calibration using a water-cooled heat flux gauge (SBG01, Hukseflux).

Figure 17 Trial to validate green roof flammability experimental setup and test sensor configurations

Results and discussion

Results show that the proposed experimental setup can provide valuable insights into multiple flammability characteristics of green roof systems. Flaming combustion and flame spread depended strongly on the system moisture and canopy continuity, with the same setup not igniting at 12% volumetric soil moisture content (VMC) but igniting at lower soil moistures of 5% VMC with strongly desiccated plants past the permanent wilting point (Figure 17). Horizontal flame spread was observed to be terminated by a gap in the dry canopy. This experimental setup enables the testing of the fire behaviour of specific green roof designs before their implementation in the field. It can generate data on i) the necessary dimensions of vegetation-free safety zones like gravel strips to stop fire spread from foliage; ii) critical soil/ and leaf moisture contents for ignition of different green roof plant species, and iii) the relative flammability of different green roof configurations to inform green roof designers and practitioners. To get a clear distinction of influencing factors that contribute to green roof flammability, the system state needs to be quantified as comprehensively as possible (soil moisture content, leaf moisture determination from samples, canopy coverage, canopy continuity, plant height). This will enable comparisons when varying green roof setups and can help to enable native plants by providing data on real-life fire performance. However, plant species will always be subject to a certain level of variation requiring sufficient replication that should be considered when providing generalised recommendations. Future use of this experimental setup can systematically optimize green roof designs by varying one parameter (plant species, planting density, substrate type, moisture contents, etc.) at a time to further understand how it affects flammability characteristics. This will aid in designing fire safe green roofs for our cities that can provide a great range of ecological, social, and environmental benefits.

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References

Abuseif, M., Dupre, K., & Michael, R.N., 2022. Trees on buildings: Opportunities, challenges, and recommendations. Building and Environment 225, 109628, https://doi.org/10.1016/j.buildenv.2022.109628.

Alam, A., Wyse, S., Buckley, H., Perry, G., Sullivan, J., Mason, N., Buxton, R., Richardson, S., & Curran, T., 2019. Shoot flammability is decoupled from leaf flammability, but controlled by leaf functional traits. Journal of Ecology 108. https://doi.org/10.1111/1365-2745.13289.

Chell, S., & Michael, R. N., 2023. Native Plants on Australian Green Roofs - Perceptions of green roof professionals [unpublished manuscript].

Chell, S., Tomson, N., Kim, T. D. H., & Michael, R. N., 2022. Performance of native succulents, forbs, and grasses on an extensive green roof over four years in subtropical Australia. Urban Forestry & Urban Greening 74, 127631, https://doi.org/10.1016/j.ufug.2022.127631.

Etlinger, M., & Beall, F., 2005. Development of a laboratory protocol for fire performance of landscape plants, International Journal of Wildland Fire 13, 479-488, https://doi.org/10.1071/WF04039.

Gerzhova, N., Blanchet, P., Dagenais, C., Ménard, S., & Côté, J., 2020. Flammability characteristics of green roofs, Buildings 10 (7), https://doi.org/10.3390/BUILDINGS10070126.

Hidalgo, J., Maluk, C., Cowlard, A., Abecassis-Empis, C., Krajcovic, M., & Torero, J., 2017. A Thin Skin Calorimeter (TSC) for quantifying irradiation during large-scale fire testing, International Journal of Thermal Sciences 112, 383-394, https://doi.org/10.1016/j.ijthermalsci.2016.10.013.

Long, A., Behm, A., Zipperer, W., Hermansen, A., Maranghides, A., & Mell, W., 2006. Quantifying and ranking the flammability of ornamental shrubs in the southern United States, Fire Ecology and Management Congress.

Murray, B., Brown, C., Murray, M., Krix, D., Martin, L., Hawthorne, T., Wallace, M., Potvin, S., & Webb, J., 2020. An Integrated Approach to Identify Low-Flammability Plant Species for Green Firebreaks, Fire 3 (2), 9-13. https://doi.org/10.3390/fire3020009.

Murray, B. R., Hardstaff, L. K., & Phillips, M. L., 2013. Differences in Leaf Flammability, Leaf Traits and Flammability-Trait Relationships between Native and Exotic Plant Species of Dry Sclerophyll Forest, PLoS One 8 (11), e79205-e79205, https://doi.org/10.1371/journal.pone.0079205.

Ramadhan, M. L., Zarate, S., Carrascal, J., Osorio, A. F., & Hidalgo, J. P., 2021. Effect of fuel bed size and moisture on the flammability of Eucalyptus saligna leaves in cone calorimeter testing, Fire Safety Journal 120, 103016, https://doi.org/10.1016/j.firesaf.2020.103016.

Weise, D. R., White, R. H., Beall, F. C., & Etlinger, M., 2005. Use of the cone calorimeter to detect seasonal differences in selected combustion characteristics of ornamental vegetation, International Journal of Wildland Fire 14 (3), 321-338, https://doi.org/10.1071/WF04035.

White, R. H., & Zipperer, W. C., 2010. Testing and classification of individual plants for fire behaviour: plant selection for the wildland–urban interface, International Journal of Wildland Fire 19, 213-227, https://doi.org/10.1071/wf07128.

On the influence of plant morphology in the extensive green roof cover: a case study in Mediterranean area

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Keywords: Crassulaceae, coverage, plant morphogenesis, phyllotaxis

ABSTRACT

The success of green roofs in Mediterranean areas requires the selection of fast development plant species, able to grow in a shallow soilless substrate also under dry climatic conditions. In this context, the exploitation of native species from marginal sites characterized by limited availability of nutrients and water could be a strategy to select plants. In this work, various species, belonging to the Crassulaceae family from Central Mediterranean and sub-tropical regions, have been evaluated for their growth performance on extensive green roofs outdoor in Central Italy in single and mixed culture. The morphology, *i.e.* branched or rosette type, resulted a fundamental trait for the coverage and species with prostrate branches, presented higher plant cover in the first year after transplant respect to the "rosette" type in single culture. In particular, the Mediterranean native branched species *S. album, S. rupestre, S. sediforme* and the "rosette" *Sempervivum tectorum* presented a good performance under the seasonal variations, with high cover ability or biomass production after 15 months. In the mixed cultures, these species presented a different performance. *S. album* resulted high competitive and invasive respect to the other *Sedums* and may be suitable for monoculture or in combination with low covering shrub species. Among the "rosette" species, the allochthonous subtropical *Aeonium castello paivae* Bolle presented a good surface coverage and biomass production respect to the branched species while the native *Sempervivum tectorum* (Griseb. & Schenk) L. presented low covering ability in all the combinations. However, the introduction of "rosette" species in combination with "branched" ones (Sedums) could increase the diversity and aesthetic appearance of the roof.

Novel computational tool for coupling water and heat transport models – application on green roofs

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Keywords: green roofs, Richards equation, Heat equation, evapotranspiration, urban heat island

ABSTRACT

Introduction: Green roofs are one of the most common multifunctional types of Nature Based Systems (NBS) serving primarily for mitigation of the urban runoff (Stovin et al. 2012, Versini et al. 2020). Since relying on the soil water interaction, green roofs also have a significant impact on reduction of the local temperature, which has not been so deterministically investigated in the past. To simulate the change of substrate temperature and water content accurately and continuously, it is necessary to couple models for water and heat transport through (un)saturated porous media which has been done in many studies (Campbell 1985, Bittelli et al. 2008). The core of these models are the partial differential equations that are strongly nonlinear, especially Richards (1931) equation describing the unsaturated water flow, and hence their numerical solving is still challenging from the perspective of the computational time, numerical stability, and accuracy. Linearization of Richards equation has first been proposed by Ross (2003) who developed a stable explicit numerical scheme for solving it by using Taylor series and Kirchhoff potential to express unsaturated water fluxes, while similar approach has not been applied yet to Heat equation. The main deficiency of this approach as far as Richards equation is concerned is the necessity to use finer time discretization to avoid greater water balance errors, as well as the complex and often inaccurate transition from the unsaturated to saturated state and vice versa.

To develop a robust and accurate numerical tool for consecutive solving of Richards and Heat equations, several improvements compared to the existing approaches have been made. Firstly, Taylor series has also been applied on soil heat fluxes creating rather simple and mathematically elegant explicit numerical scheme for solving Heat equation. Secondly, unlike in Ross's method where only the first term of Taylor series is used, here are used the first and the second term to create more accurate approximation of water fluxes. Also, unlike in Ross (2003), here Richards equation is solved strictly with respect to Kirchhoff potential to smooth the transition between unsaturated and saturated water flow. Finally, the evapotranspiration rate at the top surface is not predefined but determined from the latent heat flux computed through the iterative solving of Richards and Heat equations. Here are presented preliminary simulation results of the proposed coupled model obtained by using approximately six days long timeseries of the measured meteorological data taken from Bittelli et al. (2008).

Methodology: Richards (1931) equation is the nonlinear partial differential equation of the second order describing the (un)saturated water flow through the porous media. If water fluxes q_w [m/s] are expressed through Taylor series using Kirchhoff potential $\phi(h_k) = \int_{-\infty}^{h_k} K_w(h_k)\, dh_k$, where $K_w(h_k)$ is the soil hydraulic conductivity [m/s] described with Brooks & Corey (1964) power law relation and h_k is the soil matric potential [m], Richards equation takes the following discrete form:

$$\left(\left.\frac{\partial q_{w,i-1}}{\partial \phi_{i-1}}\right|^{k} + 0.5\left.\frac{\partial^2 q_{w,i-1}}{\partial {\phi_{i-1}}^2}\right|^{k} \Delta\phi_{i-1}^{k+1,p-1}\right)\Delta\phi_{i-1}^{k+1,p} + \left(\left.\frac{\partial q_{w,i-1}}{\partial \phi_{i}}\right|^{k} + 0.5\left.\frac{\partial^2 q_{w,i-1}}{\partial {\phi_{i}}^2}\right|^{k} \Delta\phi_{i}^{k+1,p-1} - \left.\frac{\partial q_{w,i}}{\partial \phi_{i}}\right|^{k} - 0.5\left.\frac{\partial^2 q_{w,i}}{\partial {\phi_{i}}^2}\right|^{k} \Delta\phi_{i}^{k+1,p-1} - \frac{1}{\sigma}\frac{\Delta z_i}{\Delta t}\frac{1}{D_i^{k+1,p-1}}\right)\Delta\phi_{i}^{k+1,p} - \left(\left.\frac{\partial q_{w,i}}{\partial \phi_{i+1}}\right|^{k} + 0.5\left.\frac{\partial^2 q_{w,i}}{\partial {\phi_{i+1}}^2}\right|^{k} \Delta\phi_{i+1}^{k+1,p-1}\right)\Delta\phi_{i+1}^{k+1,p} = \frac{1}{\sigma}\left(q_{w,i}^{k} - q_{w,i-1}^{k} + \frac{\Delta z_i}{\Delta t}\left(\Delta\theta_i^{k+1,p-1} - \frac{\Delta\phi_i^{k+1,p-1}}{D_i^{k+1,p-1}}\right)\right) \quad (1)$$

where $D = \frac{d\phi}{d\theta}$ is diffusivity coefficient [m²/s], and $\sigma = 0.5$ is the temporal weighting factor for unsaturated media (equal to 1.0 in case of saturation). Since using the second derivative $\frac{\partial^2 q}{\partial \phi^2}$ in Taylor series and *D* which is a function of ϕ, a system of *N* nonlinear equations (1) is formed, where *N* is the number of computational nodes along the soil depth. The system is solved iteratively (*p* indicates iteration number), and as a result $\Delta\phi_i^{k+1}$ values are obtained so that $\phi_i^{k+1} = \phi_i^k + \Delta\phi_i^{k+1}$ is determined for each node *i* = 1 to *N* at the following time step (*k+1*).

Heat equation is of the similar form as Richards equation, and hence it can be also solved through Taylor series by using solely the first derivative of the heat flux $q_{h,i} = \frac{K_{h,i}}{\Delta z_i}(T_i\text{-}T_{i+1})$ with respect to soil temperature *T*.

$$\left.\frac{\partial q_{h,i\text{-}1}}{\partial T_{i\text{-}1}}\right|_k \Delta T_{i\text{-}1}^{k+1} + \left(\left.\frac{\partial q_{h,i\text{-}1}}{\partial T_i}\right|_k \text{-} \left.\frac{\partial q_{h,i}}{\partial T_i}\right|_k \text{-} C_{h,i}\frac{\Delta z_i}{\sigma \Delta t}\right)\Delta T_i^{k+1} \text{-} \left.\frac{\partial q_{h,i}}{\partial T_{i+1}}\right|_k \Delta T_{i+1}^{k+1} = \frac{1}{\sigma}\left(q_{h,i}^k \text{-} q_{h,i\text{-}1}^k\right) \quad (2)$$

where C_h and K_h are the soil heat capacity [J/(m³ K)] and the soil heat conductivity [W/(m K)], respectively, both depending solely on soil water content θ [-], while derivatives $\frac{\partial q_h}{\partial T}$ also have the analytical form as in case of Richards equation. If Equation (2) is written for each node *i* = 2 to *N-1* with exception of *i* = 1 and *N* where boundary conditions are defined, system of *N* linear equations is solved without iterations and $T_i^{k+1} = T_i^k + \Delta T_i^{k+1}$ values are obtained.

For solving both Richards and Heat equations, it is necessary to define top and bottom boundary conditions. In case of water transport, bottom boundary condition is set as free drainage ($q_{w,N} = K_{w,N}$), while at the top surface precipitation or irrigation rate is defined as a model input, as well as the evapotranspiration rate calculated from the results of the Heat equation. Heat flux at the bottom surface is computed based on the defined temperature of a roof deck $q_{h,N} = \frac{K_{h,N}}{\Delta z_N}(T_N\text{-}T_{bott})$, while the difference $R_n - \lambda ET - H$, where R_n is the known net radiation [W/m²] while λET and *H* are the latent and the sensible heat fluxes [W/m²], respectively, is used at the top surface:

$$\lambda ET = \frac{\rho_a c_p}{\gamma}\frac{(e_s(T_1)\text{-}e_a)}{r_s + r_a}\frac{H_r(T_1)\text{-}H_a}{1\text{-}H_a} \quad (3)$$

$$H = \frac{\rho_a c_p}{r_a}(T_1\text{-}T_{air}) \quad (4)$$

where ρ_a is the air density [kg/m³] depending on the air temperature T_{air} [K] and atmospheric pressure, c_p = 1013 J/(K kg) is the specific heat of air, γ is the psychometric constant [Pa/K] depending on the atmospheric pressure, $\lambda = 2.45$ MJ/kg is the latent heat of vaporization, r_s and r_a are the soil surface and aerodynamic resistances for water vapour transfer [s/m], e_s and e_a are the vapour pressures [Pa] at the soil surface and in the air, respectively, while H_a and H_r are the relative air humidity [-] and the relative humidity at the soil surface [-], respectively.

The calculation is performed by initially solving the Heat equation with $R_n - \lambda ET - H$ used at the top boundary, where λET and *H* are expressed by means of Taylor series using the values T_i^k from the previous time step. After computing values of T_i^{k+1}, new value of λET is determined (Eq. 3) and transformed into the evapotranspiration rate ET = $\lambda ET/\lambda$ to be used as an input for Richards equation. After solving system of *N* nonlinear equations (1), ϕ_i^{k+1} and hence θ_i^{k+1} values are obtained and used again to recalculate the soil thermal properties and determine new T_i^{k+1} values. The whole procedure is iteratively repeated until the difference between λET values in two consecutive iterations becomes negligible.

Preliminary results: Figure 1 illustrates how does the soil water content affects the substrate temperature (middle graph), and the latent heat flux (bottom graph) which has the same character as the evapotranspiration rate (see Eq. 3). With solid lines is presented initially saturated substrate that is not irrigated during the simulation period, while dashed lines represent initially saturated substrate that is irrigated during six hours each day. Calculation is performed for a 20 cm thick low permeable green roof substrate (saturated hydraulic conductivity $3x10^{-6}$ m/s) with porosity 0.4. Results show strong dependence between the soil water content and both the latent heat flux and soil temperature. When the substrate is wet, the energy coming from the net radiation is mostly used for vaporization, but as soon as the substrate becomes dry this energy is mostly used for heating up the substrate. In Figure 1 this becomes evident after 90 h from the beginning of simulation, when the latent heat flux for non-irrigated substrate (solid lines in Figure 1) starts decreasing due to the lack of water, while at the same time substrate temperature starts rising significantly. On the other hand, if green roof is irrigated frequently enough (dashed lines in Figure 1) so to not allow the water content to decrease significantly (approaching the residual water content), the latent heat flux becomes larger and the substrate temperature decreases.

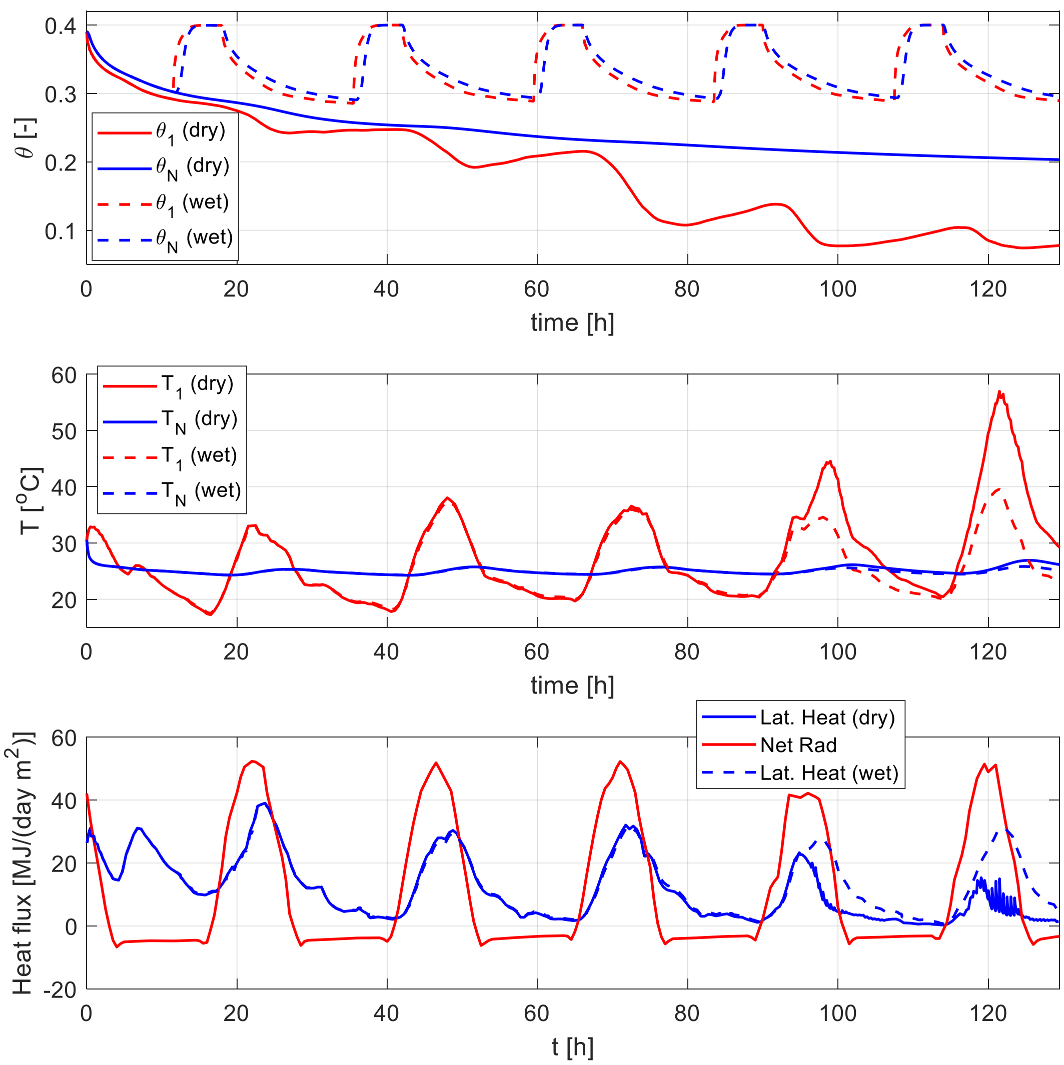

Figure 1. Change of substrate water content (top graph), substrate temperature (middle graph) and Latent Heat Flux (bottom graph) depending on whether the green roof is irrigated (dashed lines) or not (solid lines)

Due to utilization of the first and the second term of Taylor series when solving Richards equation, the calculation is more accurate but also more efficient since larger time steps are used. For the example presented here, the total water balance error (water volume per specific area) is order of magnitude of 10^{-8} m^3/m^2, while the total energy balance error is about 10^{-10} J/m^2.

Conclusion: The proposed coupled water and heat transport model relies on iterative solving of Richards equation and Heat equation with variable boundary conditions. It relies on the linearization of highly nonlinear partial differential equations by using Taylor series to express water and heat fluxes and create that way more accurate, robust, and stable numerical schemes widely applicable. Besides the numerical schemes, an innovation brought by this work is the computation of the evapotranspiration rate through the iterative determination of various energy balance components. Simulation results presented here are logical, indicating the importance of irrigation of green roofs and other similar NBS so they do not only serve as a detention element for stormwater, to mitigate floods, but also to reduce the temperature of the soil and hence to mitigate the urban heat island effect pronounced during droughts.

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References:

Bittelli M., Ventura F., Campbell G. S., Snyder R. L., Gallegati F., Pisa P. R., 2008. Coupling of heat, water vapor, and liquid water fluxes to compute evaporation in bare soils, Journal of Hydrology, 362(3–4), 191-205, DOI: 10.1016/j.jhydrol.2008.08.014

Brooks R. H., Corey A. T., 1964. Hydraulic Properties of Porous Media, Hydrology Papers, 3, 1–27.

Campbell G. S., 1985. Soil Physics with Basic – Transport Models for Soil-Plant Systems, Development in Soil Science 14, ELSEVIER, Amsterdam, Netherlands, ISBN 0-444-42557-8 (Vol. 14)

Richards L. A., 1931. Capillary conduction of liquids through porous media, Physics, 1, 318–333.

Ross P. J., 2003. Modeling Soil Water and Solute Transport – Fast, Simplified Numerical Solutions, Agronomy Journal, 95(6), 1352-1361.

Stovin, V., Vesuviano, G., and Kasmin, H., 2012. The hydrological performance of a green roof test bed under UK climatic conditions, Journal of Hydrology, 414–415, 148–161, https://doi.org/10.1016/j.jhydrol.2011.10.022

Versini P.-A., Stanic F., Gires A., Schertzer D., Tchiguirinskaia I., 2020. Measurements of the water balance components of a large green roof in the greater Paris area, Earth System Science Data, 12, 1025–1035, https://doi.org/10.5194/essd-12-1025-2020

Performance of three ornamental species for indoor living walls irrigated with greywater

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Keywords: Vertical greening systems; building integrated vegetation; water reuse; ecological treatment; wastewater; phytoremediation.

ABSTRACT

We use a great deal of water in our daily lives and most of it is wasted. Greywater refers to household wastewater produced in bathtubs, showers, or laundry machines, excluding that from toilets. There is therefore an important flow of greywater (35-120 L per capita and day) that could be reused for landscape irrigation, toilet flushing, or fire protection, provided some minimum quality standards are met (Ghaitidak and Yadav, 2013). This reuse has many advantages as it helps to reduce the volume of tap water required, while minimising at the same time the volume sent to wastewater plants.

Living walls are vertical building integrated vegetation systems that provide a wide range of known benefits (Pérez-Urrestarazu et al., 2015). They constitute an interesting strategy to introduce vegetation in the built environment, especially indoors. Given their characteristics (i.e., verticality and limited water retention capacity) they must be irrigated. The water volume consumed by living walls varies a lot (in the range between 0.5 and 20 L m^{-2} d^{-1}) according to different variables, such as the type of living wall, its location and orientation, sun and wind exposition, or irrigation scheduling (Pérez-Urrestarazu, 2021). Given these water requirements, some concerns are raised about their environmental sustainability, particularly in regions where water is scarce (Ascione et al., 2020). Therefore, the use of alternative water sources for irrigation of living walls must be explored, greywater being an excellent solution.

Currently, there are no recognised standards to use when designing living walls to treat greywater (Boano et al., 2020), or any indication of what species work better. Plant species and growing medium are considered key factors that affect treatment performance, water consumption, or aesthetics (Pradhan et al., 2019a). The number of studies involving the use of living walls as a nature-based solution for treating greywater is increasing, especially in terms of removal efficiency (Bakheet et al., 2020; Boano et al., 2020; Lakho et al., 2021). Also, different studies involving the effect of the growing media are available (Galvão et al., 2022; Pradhan et al., 2019b; Prodanovic et al., 2018, 2017). However, less attention has been paid to the impacts on the vegetation and its ability to tolerate this kind of water characteristics while maintaining a good appearance and health. This aspect is important, as living walls have a marked aesthetic purpose, specially indoors. Moreover, an adequate health and nutritional state of the plants is critical to provide other ecosystem services such as air quality improvement.

The objective of this work is twofold: to analyse how the use of greywater to irrigate indoor living walls affects different plant species (in terms of their development and appearance) and, for each one of them, to evaluate the evolution of the quality of greywater using the living wall as a recirculating biofilter.

Three different species were used for the experiments*: Philodendron hederaceum*, *Spathiphyllum wallisii* and *Nephrolepis exaltata*. Each species was planted in two felt-based living wall modules with a surface area of 0.49 m^2 (1.02 m high and 0.48 wide). The living wall module (Fytotextile®, Terapia Urbana, S.L., Seville, Spain) was made up of three layers: a waterproof one at the back, a middle geotextile layer, and an exterior polyamide one sawn to the former, configuring a grid of 7 by 3 pockets (each one of 0.14 m x

0.14 m). The plants were obtained in nurseries and had the same size. The roots were meticulously cleansed before transplanting, and the plants were inserted bareroot into the pockets, which were then filled with expanded clay, serving as growth media.

Six living wall modules were used in the experiments, two for each species. They were attached (in a random order) to a wall of the Urban Greening laboratory at the School of Agronomic Engineering of the University of Seville. As this laboratory was located in a basement, the temperature and humidity conditions were not subjected to important variations. During the experiment (November 2^{nd} to May 13^{th}), the temperature ranged between 20.6-27.8ºC and the relative humidity between 37.2 and 81.7%. No natural light was available and lighting was provided by means of six floor lamps (one per living wall) with 3 LED bulbs (8 w, 6000º K) distributed in height to provide an uniform light intensity pattern. The illuminance provided was measured with a lux meter (model 0635 0545) attached to a Testo 435-2/-4 (Testo SE & Co. KGaA, Lenzkirch, Germany), obtaining, on average, 1057 lx in each living wall.

At the bottom of each living wall, there was a 30 L water tank that contained the greywater. It was recirculated through the living wall thanks to a submerged water pump (Compact 1000, Eheim, Germany) connected to PVC holed pipes at the top of the living wall modules. Irrigation cycles of 15 minutes were performed continuously each hour. Two additional tanks with greywater, but not connected to the living walls, were used as controls. In them, instead of the biofilter, a regular filter was used (pickup 1600, Eheim, Germany).

For the experiment, synthetic greywater was used adapting the formula proposed by Lakho et al. (2021). The ingredients used were lactic acid, cellulose, sodium dodecyl sulphate, glycerol, sodium hydrogen carbonate, sodium sulphate, ammoniumdihydrogenphosphate, casein, and septic effluent (aquaculture effluent).

The living walls were initially irrigated with tap water for 3 weeks to allow for the adjustment of the plants and a correct root development throughout the geotextile layer. After that, an adaptation period with 50% of the volume of greywater the first week and 75% in the second week was carried out. Then, two different tests were performed. The first was aimed at assessing the evolution of water quality due to the use of the living walls as biofilters. It was a short-term test lasting 1 week and was repeated three times. At the beginning of each week the tanks were filled with 100% of greywater, which was completely removed at the end of it. Water quality parameters (pH, Electrical conductivity - EC, Biological Oxygen Demand - BOD, Chemical Oxygen Demand - COD, ammonium, nitrates, nitrites, phosphates, cations and majority anions) were determined when the tanks were filled and before removing the greywater. The volume of water consumed was also measured.

A second test (long-term) was performed for 10 weeks, with the aim of studying the effects on the vegetation of the constant irrigation with greywater. For that, the tanks were periodically refilled with greywater without removing the remaining volume. Plant development parameters were measured weekly and water samples were taken from each tank prior to refilling. The water quality main parameters (pH, EC, ammonium, nitrates, nitrites, and phosphates) were monitored during this test.

After the long-term test, the first short-term test was repeated with the same characteristics presented before to assess whether the influence of the living wall on water quality changed due to a long exposure to greywater.

Photographs of the plants were taken to monitor the evolution of vegetation coverage over time. For that, they were treated with the ImageJ image-processing software (Rueden et al., 2017) to determine which pixels corresponded to green cover and which to the background, and, therefore, the fraction of the LW area covered by vegetation. The health and vigour of the plants was evaluated with the Normalised Difference Vegetation Index (NDVI) (Turvey and Mclaurin, 2012), obtained weekly for each living wall module using a handheld GreenSeeker sensor (Trimble, Sunnyvale, CA, USA).

At the end of the experiments, plants were detached from the living wall and the total biomass production was measured. Subsequently, the growing media was thoroughly removed from the roots by carefully washing with tap water. Next, the aerial part was separated from the root system to obtain fresh and dry weights of both parts separately using an AH-300 precision scale (I.C.T, S.L., La Rioja, Spain). For the dry weight, the shoots and roots were dried in an oven during 48 h at 80 ºC. An LI-3100 Leaf Area Meter (Li-Cor, Nebraska, USA) was used to determine the total leaf area per living wall module, and the average Leaf Area Index (LAI) was calculated for each species. The plant nutritional status was also determined by collecting leave samples of each species to obtain their macro and micronutrients (Ca, K, Mg, Na, P, C, N, S, B, Fe, Mn) content.

The results of the short-term test showed that the average water consumption was 2 L m^{-2} d^{-1}, with no significant difference between the species studied. Regarding the evolution of water quality, the pH increased slightly from 7.69 to 8.2-8.4 (ranging from 7.7 to 8 in the control), with few differences between species. The same behaviour was observed for EC, it increased from 428 µS/cm to 496-587 µS/cm, depending on the species (481-487 µS/cm in the control). This increment was higher for *P. hederaceum*. The reduction in ammonia and nitrites was important, while the concentration of nitrates tended to increase. A reduction in phosphates was also observed, with a slight increase in NaCl. Both BOD and COD were greatly lowered, with average reductions of 87.4 % and 98.9%, respectively. *P. hederaceum* showed slightly better performance in this sense, though differences were negligible.

The second test (long-term) showed that the three species adapted well to the continuous irrigation with greywater. The mean measured NDVI values were 0.81 (±0.024), 0.85 (±0.014) and 0.9 (±0.012) for *N. exaltata*, *P. hederaceum*, and *S. wallisii*, respectively. These values did not change much with time. However, *S. wallisii* showed a slight tendency to lower the NDVI values as time passed. Also, the covering of the living wall modules also increased with time for all species, indicating that plant development continued even with adverse quality conditions of the irrigation water.

The total average final biomass of the living wall was 128.7 g of dry weight for *N. Exaltata*, 130.3 g for *P. hederaceum* and 181.1 for *S. wallisii.* The average values of LAI were 5.26, 3.52 and 3.91, respectively. Foliar element content in the three plant species changed during the greywater treatments and differences varied according to the species and elements. In *S. wallisii,* a significant increase in the Ca, Na and C% content was observed, and a similar pattern was observed for *P. hederaceum*, while for *N. exaltata,* this increase was only observed for Ca. In all species, a significant decrease of Fe content was observed. In *S. wallisii* and *P. hederaceum,* a decrease in Mn was also detected. Even if some nutrient contents decreased after greywater irrigation, the values were still in the optimal range for plant growth.

The main conclusion is that the ornamental species tested survived and developed adequately, maintaining their aesthetic value, when irrigated constantly and exclusively with greywater. However, as the water quality decreases with time, mixing the greywater with clean water is advisable. Another option is to alternate clean water irrigation events with greywater, so that the living wall plants do not show symptoms of toxicity.

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References:

Ascione, F., De Masi, R.F., Mastellone, M., Ruggiero, S., Vanoli, G.P., 2020. Green Walls, a Critical Review: Knowledge Gaps, Design Parameters, Thermal Performances and Multi-Criteria Design Approaches. Energies (Basel) 13, 2296. https://doi.org/10.3390/en13092296

Bakheet, B., Prodanovic, V., Deletic, A., McCarthy, D., 2020. Effective treatment of greywater via green wall biofiltration and electrochemical disinfection. Water Res 185, 116228. https://doi.org/10.1016/J.WATRES.2020.116228

Boano, F., Caruso, A., Costamagna, E., Ridolfi, L., Fiore, S., Demichelis, F., Galvão, A., Pisoeiro, J., Rizzo, A., Masi, F., 2020. A review of nature-based solutions for greywater treatment: Applications, hydraulic design, and environmental benefits. Science of the Total Environment. https://doi.org/10.1016/j.scitotenv.2019.134731

Galvão, A., Martins, D., Rodrigues, A., Manso, M., Ferreira, J., Silva, C.M., 2022. Green walls with recycled filling media to treat greywater. Science of The Total Environment 842, 156748. https://doi.org/10.1016/J.SCITOTENV.2022.156748

Ghaitidak, D.M., Yadav, K.D., 2013. Characteristics and treatment of greywater-a review. Environmental Science and Pollution Research 20, 2795–2809. https://doi.org/10.1007/S11356-013-1533-0/TABLES/6

Lakho, F.H., Vergote, J., Ihsan-Ul-Haq Khan, H., Depuydt, V., Depreeuw, T., Van Hulle, S.W.H., Rousseau, D.P.L., 2021. Total value wall: Full scale demonstration of a green wall for grey water treatment and recycling. J Environ Manage 298, 113489. https://doi.org/10.1016/J.JENVMAN.2021.113489

Pérez-Urrestarazu, L., 2021. Water consumption of felt-based outdoor living walls in warm climates. Urban For Urban Green 59, 127025. https://doi.org/10.1016/j.ufug.2021.127025

Pérez-Urrestarazu, L., Fernández-Cañero, R., Franco-Salas, A., Egea, G., 2015. Vertical Greening Systems and Sustainable Cities. Journal of Urban Technology 22, 65–85. https://doi.org/10.1080/10630732.2015.1073900

Pradhan, S., Al-Ghamdi, S.G., Mackey, H.R., 2019a. Greywater recycling in buildings using living walls and green roofs: A review of the applicability and challenges. Science of the Total Environment 652, 330–344. https://doi.org/10.1016/j.scitotenv.2018.10.226

Pradhan, S., Al-Ghamdi, S.G., Mackey, H.R., 2019b. Greywater treatment by ornamental plants and media for an integrated green wall system. Int Biodeterior Biodegradation 145. https://doi.org/10.1016/j.ibiod.2019.104792

Prodanovic, V., Hatt, B., McCarthy, D., Zhang, K., Deletic, A., 2017. Green walls for greywater reuse: Understanding the role of media on pollutant removal. Ecol Eng 102, 625–635. https://doi.org/https://doi.org/10.1016/j.ecoleng.2017.02.045

Prodanovic, V., Zhang, K., Hatt, B., McCarthy, D., Deletic, A., 2018. Optimisation of lightweight green wall media for greywater treatment and reuse. Build Environ 131, 99–107. https://doi.org/10.1016/J.BUILDENV.2018.01.015

Rueden, C.T., Schindelin, J., Hiner, M.C., DeZonia, B.E., Walter, A.E., Arena, E.T., Eliceiri, K.W., 2017. ImageJ2: ImageJ for the next generation of scientific image data. BMC Bioinformatics 18, 529. https://doi.org/10.1186/s12859-017-1934-z

Turvey, C.G., Mclaurin, M.K., 2012. Applicability of the Normalized Difference Vegetation Index (NDVI) in Index-Based Crop Insurance Design. Weather, Climate, and Society 4, 271–284. https://doi.org/10.1175/WCAS-D-11-00059.1

Session B3: Sustainable management of waste biomass

Deep Eutectic Solvent Pre-Treatment of Residual Biomass streams - Effects on Anaerobic Degradability

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Keywords: Anaerobic Digestion, Pre-Treatment, Deep Eutectic Solvents, Lignocellulosic Biomass

ABSTRACT

Lignocellulosic biomass residues are a valuable resource for producing renewable energy through anaerobic digestion by offering the advantage of being abundantly available. Despite their principal feasibility for biogas production, lignocellulosic biomass generally employs a lower biogas production compared to conventional energy crops (Gizińska-Górna et al., 2016; Roj-Rojewski et al., 2019). This can be attributed to the recalcitrant nature of the lignocellulosic biomolecules hindering the fast biodegradability of such substrates in anaerobic digestion processes. An approach to address this challenge is to apply pre-treatment methods to facilitate the biodegradation and thus consequently improve biogas yields. While some of these pre-treatment methods are well studied, less research was performed on the effect of deep eutectic solvents (DES) pre-treatment on biogas yield from lignocellulosic materials. The use of DES provides a novel and more environmentally friendly pre-treatment method and is also suggested as a green solvent for the extraction of value added products (Abbott et al., 2003; Kehili et al., 2022). Recent studies showed that DES pre-treatment can lead to delignification (Lima et al., 2021) and enhance lignin extraction and biomass saccharification (Wang & Lee, 2021). Associated with this, studies showed an increase of the biogas formation potential of 48 and 33 % for corn stover and rice straw, respectively (Basak et al., 2022; Olugbemide et al., 2021). However, it was observed that DES pre-treatment may facilitate but can also inhibit biogas production from lignocellulosic material (Lima et al., 2021; Olugbemide et al., 2021).

Against this background and in order to better exploit the potential of lignocellulosic residual biomass for energy production, the present research tested deep eutectic solvents as pre-treatment method for different residual biomass streams and its effect on their biodegradability and biogas production potential through anaerobic digestion in lab scale experiments.

The lignocellulosic biomass investigated were residues from the cork and pruning producing industry as well as common reed from the constructed wetlands. While anaerobic digestion of common reed has been studied and shown to be principally feasible (Gizińska-Górna et al., 2016; Roj-Rojewski et al., 2019) biogas production from olive pruning is not well studied, even though its relatively low C/N ratio represents a favourable substrate characteristic (COSTA et al., 2018; García Martín et al., 2020). A waste product of the cork industry, which has been proposed and studied for the use as biogas substrate, is cork boiling wastewater (Gonçalves et al., 2012). However, cork dust was not yet considered for biogas production.

For this study, residues from the cork industry (cork dust) and olive production (olive tree pruning), as well as common reed stalks from a constructed wetland were treated with a deep eutectic solvent consisting of choline chloride and formic acid (1:2 molar ratio) at a solid to solvent ratio of 1:10 and at 90, 110 and 130 °C for 20, 40 and 60 min, respectively. The biogas formation potential of untreated and pre-treated samples were determined in anaerobic batch tests. The biogas formation was evaluated taking the solid recovery after pre-treatment into account. To support the data interpretation, SEM images were taken and a FTIR analysis was performed to visualize and determine differences in physical structure and crystallinity of the substrates. Also, an elementary analysis of the major elements N, C, H, S and O and a compositional analysis (glucose, xylose, galactose, arabinose, mannose lignin, ash) of the samples were

carried out. Additionally, the content of solubilized sugars and phenolic content in the liquid hydrolysate was determined to evaluate the extraction of values added products.

Exemplarily, the results of the biogas formation tests of the pre-treated cork dust samples are presented in Figure 1. A significant improvement of the biogas formation was observed for samples which were treated with DES at 130 °C for 40 and 60 min. Compared to the biogas yield of the untreated sample (51.6 ± 15.9 mLN gVS-1), the cork dust treated at 130 °C for 60 min had a biogas yield of 114.9 ± 6.2 mLN gVS-1 which accounts for more than a twofold increase. This increase remains considerably high even if the loss of organic mass as a consequence of the pre-treatment (solid recovery of 75.6 %) is taken into account. The increase in biogas formation potential was associated with a significant increase in lignin and – even more pronounced – glucose content of the solid substrate after DES treatment. This effect is resulting from the solubilisation of other molecules such as xylan. Alongside this higher availability of glucose in the substrate, SEM and FTIR analyses indicated structural alterations which could explain the increased biogas yield. The highest phenolic content of 137.4 mg GAE / g was extracted from the cork dust at 110 °C and treatment for 20 min.

Overall, the findings of the present study suggest that DES treatment is an effective option for obtaining value added products such as phenols and at the same time increasing the biogas potential of various lignocellulosic biomasses.

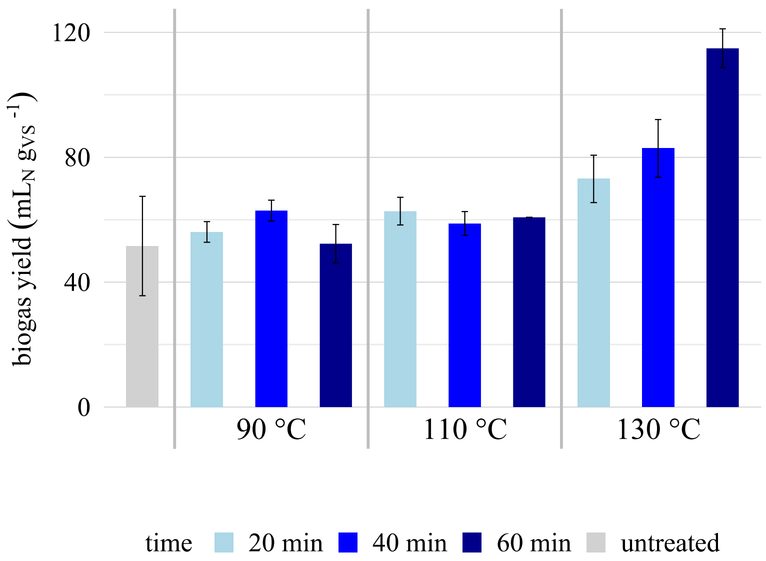

Figure 18: biogas formation potential of untreated and pre-treated cork dust samples in mL_N g_{VS}^{-1}.

Acknowledgements

This research is part of the international research project ReMe-diation (Resilient Mediterranean with a holistic approach to sustainable agriculture: Addressing challenges of water, soil, energy and biodiversity) within the PRIMA program (https://prima-med.org/), which assesses diverse socio-economic and environmental benefits of holistic agricultural systems. The concept includes intercropping and constructed wetlands for nature-based wastewater treatment, subsequent value-added product and energy production from residual biomass and – closing the loop – the use of residual digestate as bioferilizer or for biochar production. Website: https://remediationproject.com/

References:

Abbott, A. P., Capper, G., Davies, D. L., Rasheed, R. K., & Tambyrajah, V. (2003). Novel solvent properties of choline chloride/urea mixtures. Chemical Communications (Cambridge, England)(1), 70–71. https://doi.org/10.1039/B210714G

Basak, B., Patil, S., Kumar, R., Ha, G.-S., Park, Y.-K., Ali Khan, M., Kumar Yadav, K., Fallatah, A. M., & Jeon, B.-H. (2022). Integrated hydrothermal and deep eutectic solvent-mediated fractionation of lignocellulosic biocomponents for enhanced accessibility and efficient conversion in anaerobic digestion. Bioresource Technology, 351, 127034. https://doi.org/10.1016/j.biortech.2022.127034

COSTA, P., DELL'OMO, P. P., & La FROSCIA, S. (2018). Multistage milling and classification for improving both pellet quality and biogas production from hazelnut and olive pruning. Annales De Chimie Science Des Matériaux, 42(4), 471–487. https://doi.org/10.3166/acsm.42.471-487

García Martín, J. F., Cuevas, M., Feng, C.-H., Álvarez Mateos, P., Torres García, M., & Sánchez, S. (2020). Energetic Valorisation of Olive Biomass: Olive-Tree Pruning, Olive Stones and Pomaces. Processes, 8(5), 511. https://doi.org/10.3390/pr8050511

Gizińska-Górna, M., Czekała, W., Jóźwiakowski, K., Lewicki, A., Dach, J., Marzec, M., Pytka, A., Janczak, D., Kowalczyk-Juśko, A., & Listosz, A. (2016). The possibility of using plants from hybrid constructed wetland wastewater treatment plant for energy purposes. Ecological Engineering, 95, 534–541. https://doi.org/10.1016/j.ecoleng.2016.06.055

Gonçalves, M. R., Gil, L., & Marques, I. P. (2012). Cork boiling wastewater management by anaerobic digestion. 4th International Conference on Engineering for Waste and Biomass Valorization. https://repositorio.lneg.pt/handle/10400.9/1668

Kehili, M., Isci, A., Thieme, N., Kaltschmitt, M., Zetzl, C., & Smirnova, I. (2022). Microwave-assisted deep eutectic solvent extraction of phenolics from defatted date seeds and its effect on solubilization of carbohydrates. Biomass Conversion and Biorefinery. Advance online publication. https://doi.org/10.1007/s13399-022-03027-6

Lima, F., Branco, L. C., Lapa, N., & Marrucho, I. M. (2021). Beneficial and detrimental effects of choline chloride-oxalic acid deep eutectic solvent on biogas production. Waste Management (New York, N.Y.), 131, 368–375. https://doi.org/10.1016/j.wasman.2021.06.027

Olugbemide, A. D., Oberlintner, A., Novak, U., & Likozar, B. (2021). Lignocellulosic Corn Stover Biomass Pre-Treatment by Deep Eutectic Solvents (DES) for Biomethane Production Process by Bioresource Anaerobic Digestion. Sustainability, 13(19), 10504. https://doi.org/10.3390/su131910504

Roj-Rojewski, S., Wysocka-Czubaszek, A., Czubaszek, R., Kamocki, A., & Banaszuk, P. (2019). Anaerobic digestion of wetland biomass from conservation management for biogas production. Biomass and Bioenergy, 122, 126–132. https://doi.org/10.1016/j.biombioe.2019.01.038

Wang, W., & Lee, D.-J. (2021). Lignocellulosic biomass pretreatment by deep eutectic solvents on lignin extraction and saccharification enhancement: A review. Bioresource Technology, 339, 125587. https://doi.org/10.1016/j.biortech.2021.125587

Transforming biogenic waste through anaerobic digestion in achieving the circular economy

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Keywords: anaerobic digestion, biogenic waste, circular economy, sustainable agriculture

ABSTRACT

A large number of agricultural by-products and animal husbandry waste have been produced due to the inevitable agricultural practice for human survival. The utilization of agricultural and animal husbandry residues in waste-to-energy technologies has become an eye-catching issue over the years because of the concept of the circular economy for sustainable development. These biogenic residues possess a high content of organic carbon (e.g., carbohydrates, proteins, and lipids) and are being dumped into landfills or incinerated, causing severe environmental challenges and the waste of available resources. Anaerobic digestion (AD) provides a sustainable route for resource circular utilization in agriculture and husbandry waste. The dry anaerobic digestion process is adopted to treat biogenic waste including outer leaves of cabbage (C), litter (L), and pig manure (PM) in the present study. Different from the main target of past studies to enhance biomethane production, this study aimed to transform the waste into saccharides and organic acids which are the intermediates in AD processes (i.e., hydrolysis and acidogenesis phases) and can be further refined or utilized in various industries. Hence, *Saccharomyces cerevisiae* was chosen as the microbial inoculum due to its non-gas-generating characteristic. The results of batch AD experiments for 35 days showed that the optimum feedstock mass mixture ratios are C:L = 2:1, C:L = 3:1, C:PM = 2:1, and C:PM = 3:1 since the observation of more saccharides formation. Moreover, the optimal feedstock-to-inoculum ratio (F/I ratio) is 1:1 and the best AD operation temperature is 45°C. The batch experiments were scaled up to the 10 L continuously stirred reaction tank to determine the feasibility of *in situ* AD practice. In comparison to the traditional way to deal with agriculture and husbandry waste, AD is promising to be a valorized treatment to convert waste into reusable bioproducts which enables economic and environmental benefits to realize the concept of the circular economy.

INTRODUCTION

Due to the intensive cultivation conditions in agriculture and husbandry, the treatment of biogenic waste becomes an important issue for resource recycling. Biogenic waste contains a high content of nutrients such as carbohydrates, proteins, and lipids, which can be further recycled and utilized with proper treatment. However, biogenic waste used to be incinerated or composted, causing severe environmental challenges and the waste of available resources. Anaerobic digestion is a suitable way to transform macro-organic substances into biogas and digestate. Therefore, this study aimed to apply the anaerobic digestion process to transform biogenic waste and focus on the preliminary reactions, which are hydrolysis, acidogenesis, and acetogenesis, by adopting specific bacteria inoculum. Different from the main target of past AD to produce biomethane, the intermediate products (e.g., saccharides and VFAs) generated by AD are also worthy to use in various related industries. This approach achieves economic growth while minimizing environmental impact, facilitating the establishment of a sustainable circular economic model, and reducing environmental burden and energy consumption.

MATERIAL AND METHODS

In this study, three kinds of biogenic wastes, i.e., outer leaves of cabbage (C), litter (L), and pig manure (PM), were adopted as feedstock in the AD process. *Saccharomyces cerevisiae* was the chosen bacteria strain to add into the AD process to be the dominant microbial inoculum due to its non-gas generating characteristic. The AD processes were operated in both batch reactor and continuously stirred tank reactor (CSTR) with 100 mL and 5 L working volume for 35 days under controlled experimental parameters (i.e., feedstock mixture ratio, feedstock-to-inoculum (F/I) ratio, AD temperature). Samples were collected on the 7, 14, 21, 28, and 35 days after the AD reaction took place. The digestate was separated into liquid and solid form and analyzed by HPLC (e.g., saccharides and VFAs) and EA to evaluate the performance of AD conversion efficiency.

RESULTS

Effects of feedstock mixture ratios

The three types of feedstocks were mixed in different ratios to determine the effect of anaerobic digestion in batch experiments. During the first stage of the AD process, microorganisms decomposed macro-organic compounds into saccharides, amino acids, and fatty acids by hydrolysis. To determine the AD conversion efficiency, the total monosaccharides production of cellobiose, glucose, galactose, mannose, xylose, and arabinose was considered. The results showed the optimal feedstock mass mixture ratios are C:L = 2:1, C:L = 3:1, C:PM = 2:1, and C:PM = 3:1, and cabbage is the key feedstock that affects the monosaccharides production. Moreover, the hydrolysis reaction was mainly carried out in the first 21 days and then forward to the acidogenesis stage for VFAs production.

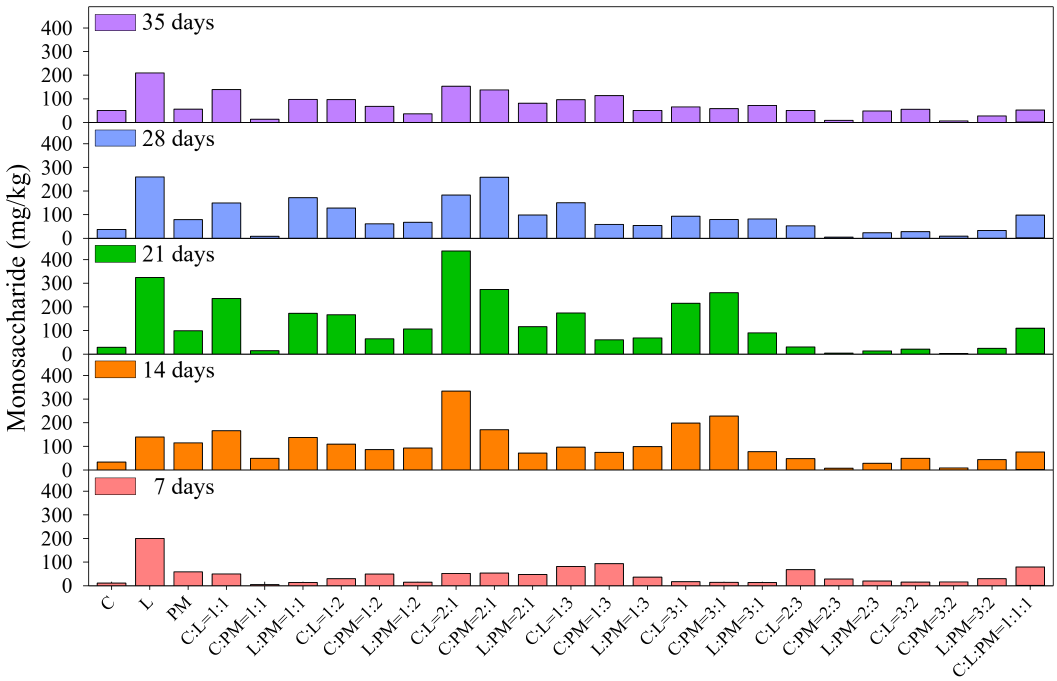

Figure 1 The monosaccharides production of different feedstock mixture ratios in batch AD.

Effects of feedstock-to-inoculum (F/I) ratio

The monosaccharides production efficiency was used to evaluate the impact of the feedstock-to-inoculum (F/I) ratio on the anaerobic digestion process. The experiment focused on the four optimal feedstock mixture ratios (i.e., C:L = 2:1, C:L = 3:1, C:PM = 2:1, and C:PM = 3:1) due to their obvious monosaccharides production. The result showed monosaccharides production efficiencies at F/I ratios of 0.5 and 2 were significantly lower than the F/I ratio of 1. This is mainly because of the water content in the batch reactor which affects the AD hydrolysis efficiency. As a result, the F/I ratio of 1 was estimated to be the most effective condition for AD transformation to monosaccharides.

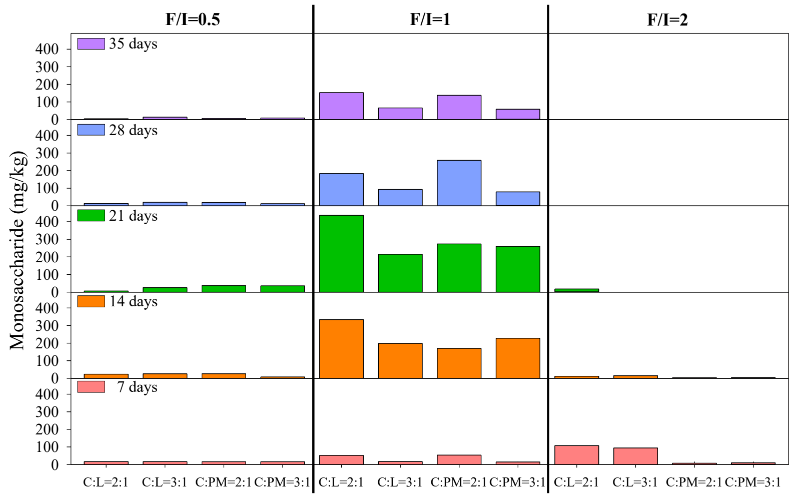

Figure 2 The monosaccharides production of different F/I ratios in batch AD.

Effects of anaerobic digestion operating temperature

To enhance the AD conversion efficiency, the proper increment of AD operating temperature could improve digestion. The experiments were conducted at four different temperatures (i.e., 37°C, 45°C, 50°C, and 55°C) at four optimal feedstock mixture ratios (C:L = 2:1, C:L = 3:1, C:PM = 2:1, and C:PM = 3:1). The AD conversion efficiency results were evaluated by the residual carbon content in solid digestate, which refer to the higher carbon conversion from feedstock to liquid digestate causing the lower carbon content remains in the solid digestate. In the feedstock mixture of cabbage and litter, the residual carbon content in solid digestate showed higher along with the temperature increment, indicating that raising the temperature is not suitable for the mixture of cabbage and litter. In the experiments containing cabbage and pig manure, the best AD conversion efficiency showed at the operating temperature of 45°C and 50°C. It may indicate the presence of other anaerobic bacterial species in pig manure, which are more suitable for growth in the moderate temperature range. In summary, different feedstock combinations are suitable for different anaerobic reaction temperatures.

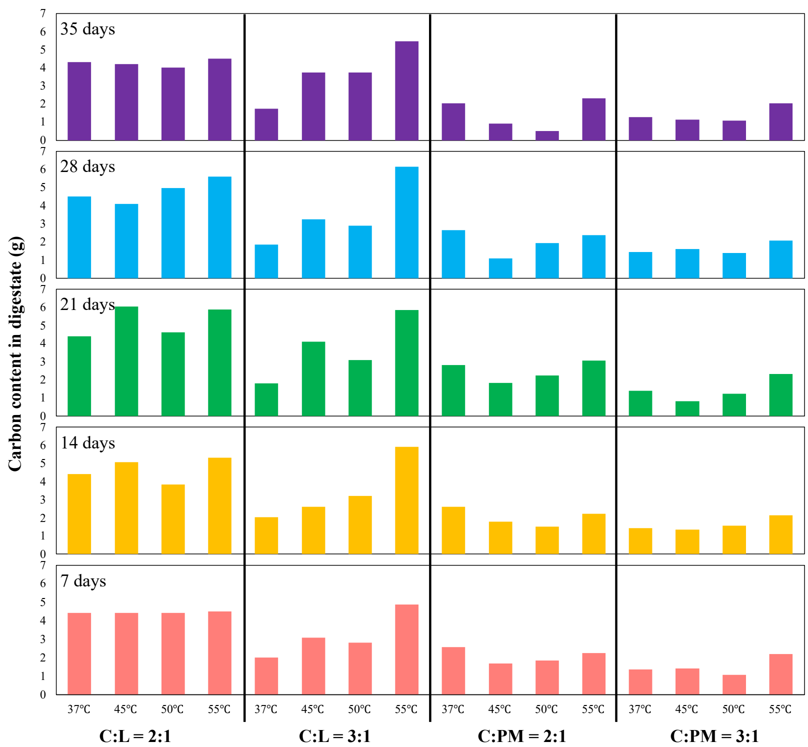

Figure 3 The carbon residual content in solid digestate at different operation temperatures in batch AD.

Effects of anaerobic digestion operating volume

The AD process at 45°C was scale-up to the 10 litter CSTR with 5 L working volume and the AD conversion efficiency affected by the operating volume was determined by the VFAs production in liquid digestate. The results showed that there is no significant difference in the carbon percentage of produced VFAs in the feedstock mixture of cabbage and litter when the process was scaled-up. In the CSTR of the feedstock ratio of cabbage and pig manure, the VFAs yield was lower compared to the batch experiments, and the trend of increasing VFAs yield over time was observed after 35 days. It is suggested that the larger reaction volume may require a longer time for the overall reaction to convert the calculated formic acid and acetic acid through anaerobic conversion.

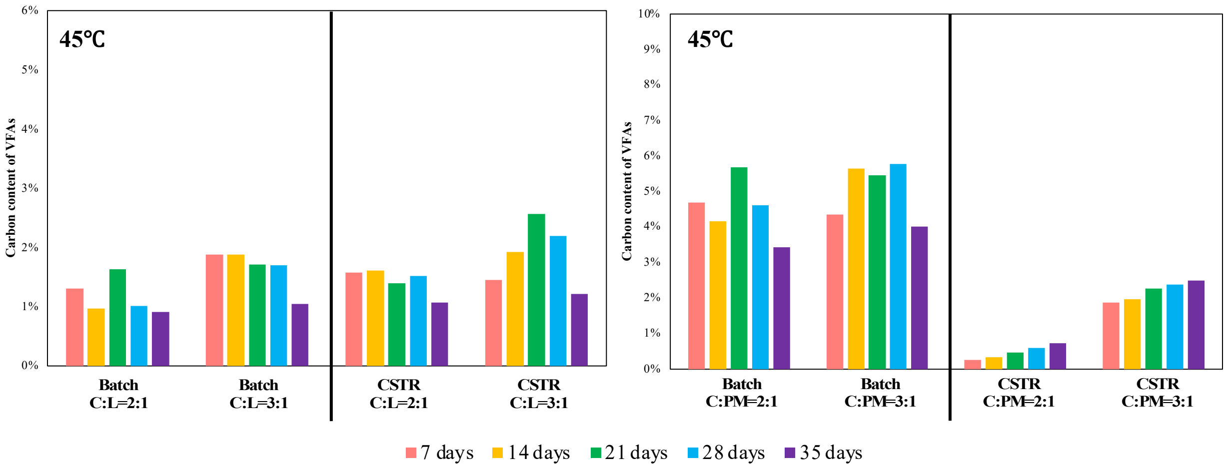

Figure 4 The carbon content of VFAs in liquid digestate in different AD operating volumes.

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References:

Akhiar, A., Battimelli, A., Torrijos, M., & Carrere, H. (2017). Comprehensive characterization of the liquid fraction of digestates from full-scale anaerobic co-digestion. *Waste Management,* 59, 118-128.

Gao, M., Zhang, S., Ma, X., Guan, W., Song, N., Wang, Q., & Wu, C. (2020). Effect of yeast addition on the biogas production performance of a food waste anaerobic digestion system. *Royal Society Open Science,* 7(8), 200443.

Hafid, H. S., Nor 'Aini, A. R., Mokhtar, M. N., Talib, A. T., Baharuddin, A. S., & Umi Kalsom, M. S. (2017). Over production of fermentable sugar for bioethanol production from carbohydrate-rich Malaysian food waste via sequential acid-enzymatic hydrolysis pretreatment. *Waste Management,* 67, 95-105.

Ning, J., Zhou, M., Pan, X., Li, C., Lv, N., Wang, T., and Zhu, G. （2019）. Simultaneous biogas and biogas slurry production from co-digestion of pig manure and corn straw: Performance optimization and microbial community shift. *Bioresource technology,* 282, 37-47.

Onwosi, C. O., Igbokwe, V. C., Odimba, J. N., Eke, I. E., Nwankwoala, M. O., Iroh, I. N., & Ezeogu, L. I. (2017). Composting technology in waste stabilization: On the methods, challenges and future prospects. *Journal of Environmental Management,* 190, 140-157.

Sawatdeenarunat, C., Nguyen, D., Surendra, K. C., Shrestha, S., Rajendran, K., Oechsner, H., Xie, L., & Khanal, S. K. (2016). Anaerobic biorefinery: Current status, challenges, and opportunities. *Bioresource Technology,* 215, 304-313.

Deep Eutectic Solvent Pretreatment of Cork Dust

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ABSTRACT

Lignocellulosic materials, such as wood and stalky biomass, have significant potential as alternative energy, material, and chemical sources. In the Mediterranean region, cork waste draws attention as a feedstock that could be utilized with various valorisation technologies to produce value-added products and energy in a biorefinery process. Cork is the outer bark of *Quercus suber L.*, the cork oak tree (Aroso et al., 2017). It is a natural, renewable, and sustainable raw material that is usually made up of suberin (30-60%), lignin (19-22%), polysaccharides (12-20%), and extractives (9-20%), such as aliphatic, phenolic, and triterpenenic compounds (Soares et al., 2014). This renewable material has a wide range of applications, the most important of which is the production of wine stoppers, followed by applications in thermal and/or acoustic insulation materials. The cork industry is an important sector in the Portuguese economy because it is the world's largest cork producer (about 157 000 tons of cork annually, representing 50% of global production) and exporter (representing 60% of global cork exports) (Santos et al. 2013). Industrial processing of raw cork yields 20 % to 30 % residue, primarily in the form of cork powder/dust with low commercial value (Mateus et al., 2016).

Chemical conversion of cork dust into a high-value product is an attractive option for increasing the overall value of the cork chain and cork oak industry sustainability (Esteves et al., 2017). The extractives present in cork and cork byproducts, particularly bioactive substances such as polyphenols and triterpenoids (e.g., friedelin), are gaining attention for their anti-inflammatory, anti-cancer, anti-oxidative, antiviral, antifungal, and antibacterial activities (Cunha et al., 2020). Therefore, instead of being burned to produce energy, this by-product could potentially be used for developing drugs, nutraceuticals, and functional foods. Several studies have utilized conventional organic solvents to extract phenolic compounds from cork dust (Reis et al., 2019; Santos et al., 2013, 2010; Touati et al., 2015). However, traditional solvents have an adverse effect on the environment, prompting scientists to seek out greener alternatives.

Deep eutectic solvents (DES) are one of the "green" solvents that can be synthesized by mixing a hydrogen bond donor (HBD) and a hydrogen bond acceptor (HBA) at a specific molar ratio capable of forming eutectic mixtures (Abbott et al., 2003). Recent research demonstrated that deep eutectic solvents (DES) may be an effective extraction medium for phenolic compounds due to their low cost, biodegradability, and non-toxicity (Kehili et al., 2022). Various investigations on deep eutectic solvent extraction of phenolic compounds from various biomass sources have been summarized in recent years (Kaoui et al., 2023). However, the use of deep eutectic solvents for the extraction of phenolic compounds from cork dust is rare in literature (Freitas et al., 2022; Rocha et al., 2023).

In light of this background, phenolic compounds were extracted from cork dust using DES. The treatment was conducted with choline chloride and formic acid (1:2 molar ratio) at various temperatures (90, 110, and 130 °C) and treatment times (20, 40, and 60 minutes) with a solid to solvent ratio of 1:10 (g/mL). The extracts obtained at 110 °C-20 minutes had the highest total phenolic content (137 mg GAE/g dry cork dust) (Figure 1). The total phenolic content yield in the liquid fractions increased with pretreatment time at low pretreatment temperatures. In addition, a rise in temperature had a positive impact on total phenolic content of the extracts. The antioxidant capacity of the optimal extracts was determined as 56.3±3.1% of DPPH inhibition. The DES treatment induced a negligible amount of sugar dissolution at low temperatures. However, under severe conditions (e.g., 130 °C for 60 minutes), approximately 42% of the xylan fraction in the biomass was degraded. Catechin, 4-hydroxybenzoic acid, and gallic acid were the most abundant phenolics in DES extracts. The surface structure of the samples was smoother after mild

pretreatment and rougher after severe pretreatment, as disclosed by SEM images. Overall, DES pretreatment was effective at extracting phenolic compounds from cork dust.

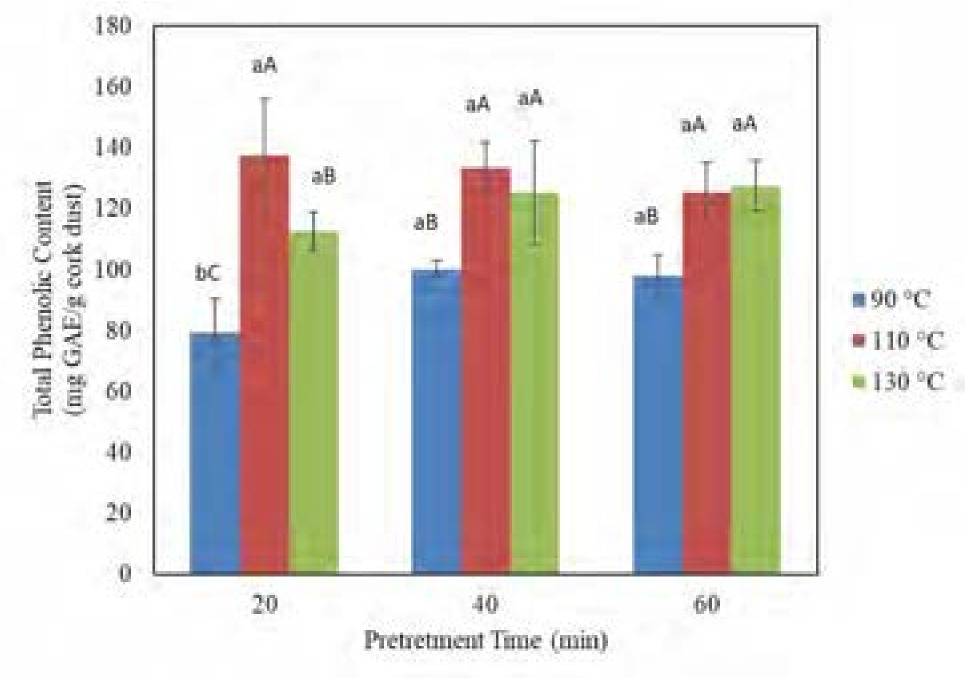

Figure 1. Change of total phenolic content in the liquid fraction with pretreatment time and temperature (Lower case letters indicate significant difference between pretreatment time and upper case letters indicate significant difference between pretreatment temperature (p<0.05)

Acknowledgements

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References

Abbott, A.P., Capper, G., Davies, D.L., Rasheed, R.K., Tambyrajah, V. (2003). Novel solvent properties of choline chlorida/urea mixtures. *Chemical Communications*, 70-71. https://doi.org/10.1039/B210714G

Aroso, I.M., Araújo, A.R., Pires, R.A., Reis, R.L. (2017). Cork: Current Technological Developments and Future Perspectives for this Natural, Renewable, and Sustainable Material. *ACS Sustainable Chemistry and Engineering, 5*(12), 11130-11146. https://doi.org/10.1021/acssuschemeng.7b00751

Cunha, M., Lourenço, A., Barreiros, S., Paiva, P., Simões, P. (2020). Valorization of cork using subcritical water. *Molecules, 25*, 4695. https://doi.org/10.3390/molecules25204695

Esteves, B. Dulyanska, Y., Costa, C., Vicente, J., Domingos, I., Pereira, H., de Lemos, L.T., Cruz-Lopes, L. (2017). Cork Liquefaction for Polyurethane Foam Production. *BioResources, 12*(2), 2339-2353. https://doi.org/10.15376/biores.12.2.2339-2353

Freitas, D.S., Rocha, D. Castro, T.G., Noro, J., Castro, V.I.B., Teixeira, M.A., Reis, R.L., Cavaco-Paulo, A., Silva, C. (2022). Green extraction of cork bioactive compounds using natural deep eutectic mixtures. ACS *Sustainable Chemistry and Engineering*, *10,* 7974-7989. https://doi.org/10.1021/acssuschemeng.2c01422

Kaoui, S., Chebli, B., Zaidouni, S., Basaid, K., Mir, Y. (2023). Deep eutectic solvents as sustainable extraction media for plants and food samples: A review. *Sustainable Chemistry and Pharmacy*, *31*, 100937. https://doi.org/10.1016/j.scp.2022.100937

Kehili, M., Isci, A., Thieme, N., Kaltschmitt, M., Zetzl, C., Smirnova, I. (2022). Microwave-assisted deep eutectic solvent extraction of phenolics from defatted date seeds and its effect on solubilization of carbohydrates. *Biomass Conversion and Biorefinery.* Advance online publication. https://doi.org/10.1007/s13399-022-03027-6

Mateus, M.M., Bordado, J.C., dos Santos, R.G. (2016). Potential biofuel from liquefied cork – Higher heating value comparison, *Fuel, 174*, 114-117. https://doi.org/10.1016/j.fuel.2016.01.081

Reis, S., Lopes, P., Roseira, I., Cabral, M., Mateus, N., Freitas, V. (2019). Recovery of added value compounds from cork industry by-products, *Industrial Crops and Products*, *140*,111599, https://doi.org/10.1016/j.indcrop.2019.111599

Rocha, D., Freitas, D.S., Magalhães, J., Fernandes, M., Silva, S., Noro, J., Ribeiro, A., Cavaco-Paulo, A., Martins, M., Silva, C. (2023). NADES-based cork extractives as green ingredients for cosmetics and textiles. *Processes*, *11*(2), 309, https://doi.org/10.3390/pr11020309

Santos, S.A.O., Pinto, P.C.R.O., Silvestre, A.J.D., Neto, C.P. (2010). Chemical composition and antioxidant activity of phenolic extracts of cork from Quercus suber L. *Industrial Crops and Products*, *31*(3), 521-526. https://doi.org/10.1016/j.indcrop.2010.02.001

Santos, S.A.O., Villaverde, J.J., Sousa, A.F. Coelho, J.F.J., Neto, C.P., Silvestre, A.J.D. (2013). Phenolic composition and antioxidant activity of industrial cork by-products. *Industrial Crops and Products, 47,* 262-269. https://doi.org/10.1016/j.indcrop.2013.03.015

Soares, B., Gama, N., Freire, C., Barros-Timmons, A., Brandão, I., Silva, R., Neto, C.P., Ferreira, A. (2014). Ecopolyol Production from Industrial Cork Powder via Acid Liquefaction Using Polyhydric Alcohols. *ACS Sustainable Chemistry and Engineering, 2*(4), 846-854. https://doi.org/10.1021/sc400488c

Touati, R., Santos, S.A.O., Rocha, S.M., Belhamel, K., Silvestre, A.J.D. (2015). The potential of cork from Quercus suber L. grown in Algeria as a source of bioactive lipophilic and phenolic compounds. *Industrial Crops and Products, 76*, 936-945. https://doi.org/10.1016/j.indcrop.2015.07.074

Potential applications of hazelnut industry waste based on material properties.

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Keywords: hazelnut, shell, characterization, application, valorization.

ABSTRACT

Hazelnuts are one of the world's leading nuts. Corylus avellana L. is the European hazelnut and it grows in many countries like Turkey (63% of the total production and 59% of exports), Italy (8% of total production and 11% of exports) or Azerbaijan (6% of total production and 6% of exports) (FAOSTAT, 2023; Pérez-Armada et al., 2019). The 90% of the hazelnuts are intended for processing in chocolate, confectionery, pastry, as well as in the preparation of numerous liqueurs and foods. In-shell hazelnuts must be opened in order to be incorporated into the industrial food chain (Puliga et al., 2022). One of the main downsides associated with hazelnut process are the by-products originated from the hazelnut industry during the harvesting, shelling, and transformation processes. The hazelnut shell (HS), the residual woody biomass resulting from the cracking process, represents approximately 50-55% of the total nut weight. The economic valorization of these by-products is attractive to the industry. However, the HS only have direct commercial value as boiler fuel and mulch presently. High-added value ingredients can be obtained from the HS, which are potentially very abundant, valuable, and cheap by-product (Fuso et al., 2021; Pérez-Armada et al., 2019; Puliga et al., 2022).

In recent decades, awareness and concern about environmental issues have increased. The constant development of modern society and technology has produced several problems like climate change or the scarcity of natural resources. The agricultural industry generates toons of biomass worldwide each year which can be considered one of the most plentiful, cheapest, and easily renewable resources on the planet (Barczewski et al., 2019; Santana-Méridas et al., 2012). Researchers are continuously striving to find new methods and strategies for valorizing agro-waste, like HS, because its use provides low-cost biodegradable raw materials, creates income and generates employment, and also, avoids the damaging effects of untreated agricultural residues (Gupta et al., 2022).

This study is focused on the search for industrial applications for HS. The hazelnuts used in this research have been cultivated in the village of Ayerbe (Huesca, Spain) and they are hand-picked hazelnuts from a local farmer, grown naturally without fertilizers or pesticides. The shells were obtained by splitting the hazelnuts with a manual cracker.

One of the main objectives of this study is a complete characterization of the material. This allows to take advantage of its maximum potential thanks to the knowledge of its properties which permits to consider the most suitable option for its use. For instance, elemental and immediate analysis provides interesting information for hazelnut agronomic valorization, such as nitrogen, fixed carbon, and ashes content. Due to this characterization, an identification of materials with similar characteristics can be made, which is a useful aid in discovering and analyzing the possible applications of HS.

The methodology utilized to achieve the proposed objectives is an adaptation of the methodology presented by (Manríquez-Altamirano et al., 2021) (see Figure 1). This method presents several phases, the first step consists of gathering information about the shell, then a characterization of the material is performed and finally, possible potential applications are identified. For the compilation of information, a

literature review has been done through different catalogs (Google Scholar, Web of Science and Scopus) with the objective of summarizing data on the material properties and its potential applications. After the collection of information, the shell was characterized by its physical and chemical properties. The mechanical characterization was discarded due to the impossibility of obtaining experimental results because of the nature of the material itself and the absence of data in the bibliography. Once the material has been fully characterized, other materials with similar characteristics to those of HS were identified by scientific literature. This is intended to allow a better understanding of the material and, through similarity to other materials, to achieve a better valorization of the product. Finally, an identification and proposal of applications are performed. Two strategies are used for this purpose: on the one hand, thanks to material characterization, applications are proposed based on its properties; and, on the other hand, by identifying similar materials, applications that also fit the material can be detected. One of the main advantages of the methodology presented is that thanks to the complete characterization of the material, which allows the identification of materials with similar characteristics, the proposition and identification of applications can be done in two ways. It is possible to find applications based on the properties of the material and, also, applications can be found and adapted based on applications of materials with similar characteristics.

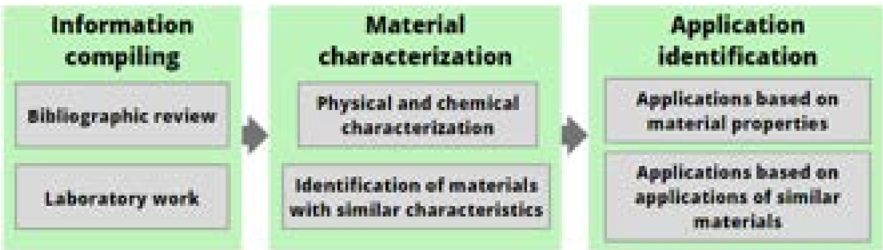

Figure 1. Methodology adapted from (Manríquez-Altamirano et al., 2021).

The results of the chemical and physical characterization of HS and its applications found on scientific literature are summarized in Table 1 and Table 2. Major components in the HS in order of content are lignin, cellulose, and hemicellulose. High heat of combustion and low ash content are two of HS most outstanding characteristics.

Table 1. Chemical and physical characterization of hazelnut shell

		Shell	Reference
Physical characterization	Moisture [%]	8.93-10.04	(Demirkaya et al., 2019; Gozaydin & Yuksel, 2017; Midilli et al., 2000)
	Ash [%]	1.35-1.48	
	Heat of combustion [kcal/kg]	4060-4645	(Dogru et al., 2002; Ferrero, 2007; Karatas et al., 2013; Midilli et al., 2000)
	Mass [g]	1.15	(Bonisoli et al., 2015)
	Absolute density [kg/m^3]	721-945	(Bonisoli et al., 2015; Dogru et al., 2002)
	Bulk density [kg/m^3]	320	(Dogru et al., 2002)
Chemical characterization	Cellulose [%]	18.24-36.02	(Cimino et al., 2000; Cruz-Lopes et al., 2012; Demirkaya et al., 2019; Gozaydin & Yuksel, 2017; Midilli et al., 2000; Pehlivan et al., 2009; Pérez-Armada et al., 2019; Rivas et al., 2020; Şenol, 2019)
	Hemicellulose [%]	11.3-32.28	
	Lignin [%]	30.2-48.57	
	Fixed carbon [%]	19.43-27.12	(Dogru et al., 2002; Karatas et al., 2013; Midilli et al., 2000; Solís et al., 2023)
	Volatile matter [%]	62.7-79.22	
	C [%]	46.76-55.48	(Cimino et al., 2000; Dogru et al., 2002; Gozaydin & Yuksel, 2017; Karatas et al., 2013; Midilli et al., 2000; Solís et al., 2023)
	H [%]	4.92-6.76	
	N [%]	0.22-1.4	
	O [%]	36.45-45.83	

Numerous and varied applications have been found for HS. However, due to being a lignocellulosic material and to its heat of combustion, the most relevant and currently developed applications are the production of fiberboards, biosorbents and energy generation.

Table 2. Hazelnut shell applications found in the scientific literature.

Application	Important properties	Reference
Animal feed	Phenolic compounds, chemical composition, dry matter, ash, lignin	(Salami et al., 2019)
Fiberboards	Cellulose, hemicellulose, lignin, ash, moisture	(Çöpür et al., 2008; Cruz-Lopes et al., 2012)
Composites	Chemical composition, moisture, density, cellulose, hemicellulose, lignin	(Barczewski et al., 2019; Demirer et al., 2018)
Bioactive compounds	Cellulose, hemicellulose, lignin, ash, moisture, chemical composition	(Fuso et al., 2021; Pérez-Armada et al., 2019; Santana-Méridas et al., 2012)
Biosorbent	Ash, chemical composition, cellulose, lignin, density, hemicellulose, moisture, pH, porosity, calorific value	(Cimino et al., 2000; Ferrero, 2007; Pehlivan et al., 2009)
Substrate	Lignin, cellulose, hemicellulose	(Puliga et al., 2022)
Fertilizer	Cellulose, hemicellulose, lignin, ash, moisture, chemical composition	(Chojnacka et al., 2020)
Renawable fuels	Cellulose, hemicellulose, lignin, ash, moisture, chemical composition, calorific value, organic matter, fixed carbon	(Demirkaya et al., 2019; Gozaydin & Yuksel, 2017; Hoşgün et al., 2017; Midilli et al., 2000; Solís et al., 2023)
Biogas	Ash, volatile matter, fixed carbon, pH, moisture, density, chemical composition, calorific value, cellulose, lignin, hemicellulose	(Dogru et al., 2002; Karatas et al., 2013; Şenol, 2019)

Based on the existing body of knowledge, this study is the first to propose a methodology for the characterization and valorization of agro-waste, specifically HS. In contrast to the traditional use of biomass, like burning, this study focused on finding applications that add value to agricultural residues which allows to use it as a higher quality eco-material. In addition, this research provided information on the physical and chemical characterization of the HS that could be helpful for other research lines. There are studies that offers data on the different parts of the hazelnut such as the husk to biomass (Çöpür et al., 2008), the leaves to animal feed (Renna et al., 2020), the kernel to cosmetics and oils (Guiné & Correia, 2020) or the skin to animal feed or fertilizer (Chojnacka et al., 2020; Renna et al., 2020). Nevertheless, although there are studies which provide data in particular of the HS, these have different perspectives, for example, the adsorption of heavy metals and dyes (Cimino et al., 2000; Ferrero, 2007), the development of cracking machinery (Bonisoli et al., 2015), to produce hydrogen, ethanol or renewable fuels (Hoşgün et al., 2017; Midilli et al., 2000; Solís et al., 2023). Some studies were found focus on the production of phenolic compounds and activated natural ingredients from shell, which are considered renewable additives for biofuels production (Pérez-Armada et al., 2019; Rivas et al., 2020). There are some studies where HS is used, mixed with other materials in different proportions, to produce fiberboards and composites (Barczewski et al., 2019; Çöpür et al., 2008).

In summary, this study aims to develop a product with the HS with the objective of create a high-quality material and add value to this abundant and cheap agricultural residue. Starting from this study, future research is proposed to improve and extend the characterization of the material and to compare it with other materials with similar properties. From there, identify the current applications of these materials, and test the suitability of HS for those applications. Then, it is proposed to carry out an ideation process together with experts from different fields (materials, environment, design, manufacturing, processes, etc.) to generate new product ideas and evaluate their technical and economic feasibility.

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References

Barczewski, M., Sałasińska, K., & Szulc, J. (2019). Application of sunflower husk, hazelnut shell and walnut shell as waste agricultural fillers for epoxy-based composites: A study into mechanical behavior related to structural and rheological properties. *Polymer Testing*, *75*, 1–11. https://doi.org/10.1016/j.polymertesting.2019.01.017

Bonisoli, E., Delprete, C., Sesana, R., Tamburro, A., & Tornincasa, S. (2015). Testing and simulation of the three point bending anisotropic behaviour of hazelnut shells. *Biosystems Engineering*, *129*, 134–141. https://doi.org/10.1016/j.biosystemseng.2014.10.002

Chojnacka, K., Moustakas, K., & Witek-Krowiak, A. (2020). Bio-based fertilizers: A practical approach towards circular economy. In *Bioresource Technology* (Vol. 295). Elsevier Ltd. https://doi.org/10.1016/j.biortech.2019.122223

Cimino, G., Passerini, A., & Toscano, G. (2000). Removal of toxic cations and Cr(VI) from aqueous solution by hazelnut shell. *Wat. Res.*, *34*(11), 2955–2962. www.elsevier.com/locate/watres

Çöpür, Y., Güler, C., Taşçioğlu, C., & Tozluoğlu, A. (2008). Incorporation of hazelnut shell and husk in MDF production. *Bioresource Technology*, *99*(15), 7402–7406. https://doi.org/10.1016/j.biortech.2008.01.021

Cruz-Lopes, L., Martins, J. M., Esteves, B., & Teixeira De Lemos, L. (2012). *New products from hazelnut shell*. https://www.researchgate.net/publication/233988360

Demirer, H., Kartal, I., Yildirim, A., & Büyükkaya, K. (2018). The utilisability of ground hazelnut shell as filler in polypropylene composites. *Acta Physica Polonica A*, *134*(1), 254–256. https://doi.org/10.12693/APhysPolA.134.254

Demirkaya, E., Dal, O., & Yüksel, A. (2019). Liquefaction of waste hazelnut shell by using sub- and supercritical solvents as a reaction medium. *Journal of Supercritical Fluids*, *150*, 11–20. https://doi.org/10.1016/j.supflu.2019.03.019

Dogru, M., Howarth, C. R., Akay, G., Keskinler, B., & Malik, A. A. (2002). Gasification of hazelnut shells in a downdraft gasifier. In *Energy* (Vol. 27). www.elsevier.com/locate/energy

FAOSTAT. (2023, June 21). *FAO*. https://www.fao.org/faostat/es/#data

Ferrero, F. (2007). Dye removal by low cost adsorbents: Hazelnut shells in comparison with wood sawdust. *Journal of Hazardous Materials*, *142*(1–2), 144–152. https://doi.org/10.1016/j.jhazmat.2006.07.072

Fuso, A., Risso, D., Rosso, G., Rosso, F., Manini, F., Manera, I., & Caligiani, A. (2021). Potential valorization of hazelnut shells through extraction, purification and structural characterization of prebiotic compounds: A critical review. In *Foods* (Vol. 10, Issue 6). MDPI AG. https://doi.org/10.3390/foods10061197

Gozaydin, G., & Yuksel, A. (2017). Valorization of hazelnut shell waste in hot compressed water. *Fuel Processing Technology*, *166*, 96–106. https://doi.org/10.1016/j.fuproc.2017.05.034

Guiné, R. P. F., & Correia, P. M. R. (2020). Hazelnut: A Valuable Resource. *ETP International Journal of Food Engineering*, 67–72. https://doi.org/10.18178/ijfe.6.2.67-72

Gupta, N., Mahur, B. K., Izrayeel, A. M. D., Ahuja, A., & Rastogi, V. K. (2022). Biomass conversion of agricultural waste residues for different applications: a comprehensive review. In *Environmental Science and Pollution Research* (Vol. 29, Issue 49, pp. 73622–73647). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/s11356-022-22802-6

Hoşgün, E. Z., Berikten, D., Kıvanç, M., & Bozan, B. (2017). Ethanol production from hazelnut shells through enzymatic saccharification and fermentation by low-temperature alkali pretreatment. *Fuel*, *196*, 280–287. https://doi.org/10.1016/j.fuel.2017.01.114

Karatas, H., Olgun, H., & Akgun, F. (2013). Experimental results of gasification of cotton stalk and hazelnut shell in a bubbling fluidized bed gasifier under air and steam atmospheres. *Fuel*, *112*, 494–501. https://doi.org/10.1016/j.fuel.2013.04.025

Manríquez-Altamirano, A., Sierra-Pérez, J., Muñoz, P., & Gabarrell, X. (2021). Identifying potential applications for residual biomass from urban agriculture through eco-ideation: Tomato stems from rooftop greenhouses. *Journal of Cleaner Production*, *295*. https://doi.org/10.1016/j.jclepro.2021.126360

Midilli, A., Rzayev, P., Olgun, H., & Ayhan, T. (2000). Solar hydrogen production from hazelnut shells. In *International Journal of Hydrogen Energy* (Issue 25, pp. 723–732). www.elsevier.com/locate/ijhydene

Pehlivan, E., Altun, T., Cetin, S., & Iqbal Bhanger, M. (2009). Lead sorption by waste biomass of hazelnut and almond shell. *Journal of Hazardous Materials*, *167*(1–3), 1203–1208. https://doi.org/10.1016/j.jhazmat.2009.01.126

Pérez-Armada, L., Rivas, S., González, B., & Moure, A. (2019). Extraction of phenolic compounds from hazelnut shells by green processes. *Journal of Food Engineering*, *255*, 1–8. https://doi.org/10.1016/j.jfoodeng.2019.03.008

Puliga, F., Leonardi, P., Minutella, F., Zambonelli, A., & Francioso, O. (2022). Valorization of Hazelnut Shells as Growing Substrate for Edible and Medicinal Mushrooms. *Horticulturae*, *8*(3). https://doi.org/10.3390/horticulturae8030214

Renna, M., Lussiana, C., Malfatto, V., Gerbelle, M., Turille, G., Medana, C., Ghirardello, D., Mimosi, A., & Cornale, P. (2020). Evaluating the suitability of hazelnut skin as a feed ingredient in the diet of dairy cows. *Animals*, *10*(9), 1–23. https://doi.org/10.3390/ani10091653

Rivas, S., Moure, A., & Parajó, J. C. (2020). Pretreatment of hazelnut shells as a key strategy for the solubilization and valorization of hemicelluloses into bioactive compounds. *Agronomy*, *10*(6). https://doi.org/10.3390/agronomy10060760

Salami, S. A., Luciano, G., O'Grady, M. N., Biondi, L., Newbold, C. J., Kerry, J. P., & Priolo, A. (2019). Sustainability of feeding plant by-products: A review of the implications for ruminant meat production. In *Animal Feed Science and Technology* (Vol. 251, pp. 37–55). Elsevier B.V. https://doi.org/10.1016/j.anifeedsci.2019.02.006

Santana-Méridas, O., González-Coloma, A., & Sánchez-Vioque, R. (2012). Agricultural residues as a source of bioactive natural products. In *Phytochemistry Reviews* (Vol. 11, Issue 4, pp. 447–466). Kluwer Academic Publishers. https://doi.org/10.1007/s11101-012-9266-0

Şenol, H. (2019). Biogas potential of hazelnut shells and hazelnut wastes in Giresun City. *Biotechnology Reports*, *24*. https://doi.org/10.1016/j.btre.2019.e00361

Solís, A., Rocha, S., König, M., Adam, R., Garcés, H. O., Candia, O., Muñoz, R., & Azócar, L. (2023). Preliminary assessment of hazelnut shell biomass as a raw material for pellet production. Fuel, 333. https://doi.org/10.1016/j.fuel.2022.126517

Wool of Mountain Sheep - Maximizing Resources Utilisation

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Keywords: sheep wool, waste, fertilizers, felt, yarns

ABSTRACT

Sheep farming in mountainous areas seems to be a natural economic activity. It has a long tradition in the Polish Carpathians where the pastoral know-how was introduced several centuries ago by Wallachian tribes who developed a transhumance pastoralism based on the seasonal flocks' migration between summer mountainous pastures and winter lowland ones. Over the centuries sheep were an integral component of the mountain landscape and ecosystem, while pastoralism became a vital part of highlander culture and economy. Transhumant pastoralism adapted to the local climate and vegetation enabled the sustainable production of several sheep products.

For a long time, wool was a relevant and precious product obtained from mountain sheep. Processed with traditional methods that have been passed down from generation to generation, wool was applied for the production of felts and hand-spun yarns which were used for manufacturing some parts of highlander clothes and costumes. In the industrial period wool was also used for the production of woollen fabrics and blankets as well as knitting yarns for handicraft. Contrary to fine merino wool, the wool from Polish mountain sheep is heterogenous, rough, difficult to spin and mass-produce. From sheep to sheep, the wool varies greatly in terms of fibre length, diameter as well as kemp and guard hair content, which significantly impairs textile properties. Generally, the kemp and guard hair content is relatively high, with guard hairs being responsible for the itching effect in wool fabrics. Kemp's brittle fibres are released in the form of fibre dust not only from semi-products during wool processing, but also from the textiles in everyday use. In addition, kemp does not take dyes well, which is significant if textile dyeing is planned. Due to its characteristics, the wool is not attractive for clothing production and consequently for the textile industry and craft sectors. For most purposes it has been replaced by synthetic fibres or even merino wool, which was also affected by the low-demand crisis. Nevertheless, regardless of its origin, wool has a number of valuable properties. It provides good thermal and sound insulation [Patnaik], is self-extinguishing and difficult to ignite [Cardamone, 2013], hygroscopic [Curling 2012], [Hegyi, 2021], biodegradable [Korniłowicz, 2011], [Broda, 2016] and absorbs volatile organic compounds well [Mansour, 2016]. In other words, it may be used as an effective raw material for numerous purposes.

At the moment sheep are kept in the Carpathians for meat as well as milk used for the production of regional cheese. The wool is classified as a by-product of sheep husbandry [Regulation, 2009] but in fact it is a troublesome waste. The amount of wool is simultaneously too small to generate interest in a big industry and too big not to generate a problem with its utilization. Thus, the raw wool is unnecessarily stored or just thrown away.

The research aiming at maximizing the utilization of local resources of wool obtained from mountain sheep was carried out. The authors were guided by the idea that "waste is not waste until we waste it". The subject of the study was wool from sheep raised in Southern Poland, in the part of Carpathians called the Silesian Beskids. The flock consisted of several hundred mountain-bred sheep. Raised mainly for milk, these sheep were diverse in terms of wool colour and quality.

The activity crucial for the aim of the research was to sort the wool according to clearly visible criteria, namely its natural colour, degree of purity and origin from the sheep's body parts. The dark and white fleeces were separated and some fragments of the fleeces – consisting of short, coarse, heavily faeces-contaminated and felted fibres – were removed just after sheep shearing. Thus, from a textile point of view, the wool was divided into wool for textile processing and waste wool. Both types of fibre were managed, each in a different way. In order to make even more efficient use of textile wool, the authors conducted a detailed review of the fleeces to estimate the guarded hair and kemp content of the wool. The extremely kemp-rich fleeces were used along with the waste wool. Fig.1 shows a diagram of wool distribution.

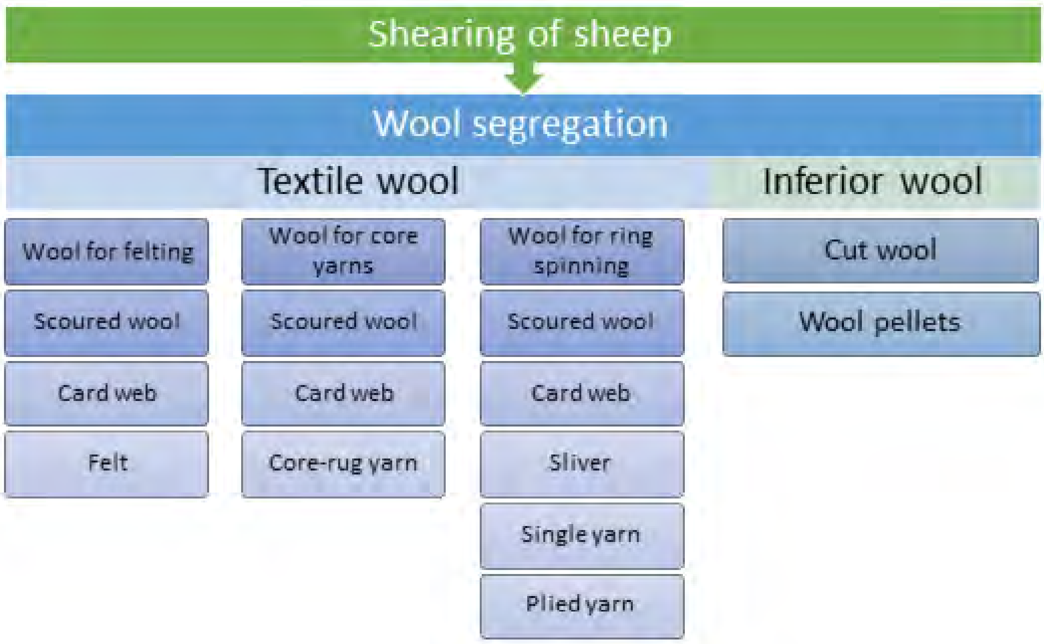

Fig.1. Distribution of wool to maximize its use.

The sorted textile wool was scoured and dried. Before carding, the authors inspected the wool for the last time and removed fine impurities and felted fibres by hand. Carding was the basic operation for different textile processes. Subsequent operations depended on the type of end product as well as wool quality. The processing of the wool into felts and yarns was carried out at the small family-owned Selbu Spinneri spinning mill (Klæbu, Norway), which specialises in processing different types of wool from native sheep.

Textile wool with the highest content of kemp was designated for felting**.** Felt was made of several layers of card web laid crosswise over each other. The felting tests carried out on a plate machine showed that the wool from mountain sheep is suitable for felting, as the kemp is tightly trapped in the compact felted material. Such felt has good properties for various uses, mainly technical ones.

Wool with predominantly long, coarse guard hair was processed into rug-core yarn. The yarn was formed by wrapping a card web around a relatively thin wool waste yarn. Such yarns have diameters of approx. 8-12 mm and a linear density of approx. 4-5 ktex. Due to their large thickness, core-rug yarns are suitable especially for handicraft techniques such as weaving and big-knit but may also be used in hand tufting (Fig 2. a).

The wool selected as having the best quality was designed for ring spinning. The slivers formed in the last stage of carding were joined together in threes and drawn. The process was repeated. The formation of ring-spun yarns included the production of single yarn in the spinning process, the formation of plied yarn in the twisting process, twist stabilization and yarn rewinding. Ring-spun yarns with linear densities in the range of 1100 - 1350 tex were eventually produced. They were tested in tufting, weaving and knitting. The suitability of ring-spun yarns in hand tufting and mechanical weaving was demonstrated (Fig 2. b).

The wool rejected as unsuitable for textile processing was used in agriculture and horticulture as a fertilizer. Agricultural and horticultural tests were carried out on a small farm in the Cieszyn Foothills (Poland). Chemical analysis for heavy metals, polycyclic hydrocarbons and other harmful substances has shown that tested wool is safe for fertilizing food crops [Broda, 2023]. Cut fibres were tested in the cultivation of tomatoes, potatoes, winter wheat (Fig 2. c) and northern highbush blueberry. Indicators of tomatoes, potatoes and wheat health and their yields showed that wool is an effective slow-release fertilizer. Moreover, the tests of northern highbush blueberry showed that the wool fertiliser does not change soil acidity. Some of the cut wool was formed into pellets, which are more convenient for use and more attractive commercially. The first trials with pellet wool were conducted.

a/ b/ c/

Fig 2. Selected forms of processed wool and their applications: a) core-rug yarns used in tufting, b) ring-spun yarn used in tufting, c) cut wool fertilizer used in agriculture.

In this way, all the wool from the shearing has been used for various purposes depending on its parameters. The key prerequisite for its maximum use is its proper separation in terms of the degree of impurity and quality directly at shearing. Accurate segregation of wool for various purposes corresponds to the highest level in the waste management hierarchy according to the European Union guidelines [Regulation, 2019], [Sigaard, 2022]. The portion of the wool of better quality is suitable for textile processing and it can be included in the wool value chain and used in local small-scale production to make felt and yarn, especially rug yarn for tufted rugs and carpets. From the point of view of textile processing waste wool, the second portion can be used for the production of wool-based fertilisers. Additional sorting of textile wool with a focus on the more subtle characteristics of the fibre allows for its most rational use in the production of yarns with differentiated properties. All the wool forms presented show market potential. It was therefore shown that there is no bad wool, only bad utilisation.

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References:

Broda, J., Kobiela-Mendrek, K., Rom, M., Grzybowska-Pietras, J., Przybylo, S., Laszczak, R. (2016). Biodegradation of Wool Used for the Production of Innovative Geotextiles Designed to Erosion Control. In: Fangueiro, R., Rana, S. (eds) Natural Fibres: Advances in Science and Technology Towards Industrial Applications. RILEM Bookseries, vol 12. Springer, Dordrecht. https://doi.org/10.1007/978-94-017-7515-1_27

Cardamone, J.M., 2013. Flame resistant wool and wool blends, Editor(s): F. Selcen Kilinc, In Woodhead Publishing Series in Textiles, Handbook of Fire Resistant Textiles, Woodhead Publishing, 245-271, https://doi.org/10.1533/9780857098931.2.245.

Curling, S.F., Loxton, C., Ormondroyd, G.A., 2012. A rapid method for investigating the absorption of formaldehyde from air by wool. Journal of Material Science 47, 3248–3251, https://doi.org/10.1007/s10853-011-6163-7

Del Rey, R., Uris, A., Alba, J., & Candelas, P. (2017). Characterization of Sheep Wool as a Sustainable Material for Acoustic Applications. Materials (Basel, Switzerland), 10(11), 1277. https://doi.org/10.3390/ma10111277

Hegyi, A.; Bulacu, C.;Szilagyi, H.; Lăzărescu, A.-V.; Meiţă , V.; Vizureanu, P., Sandu, M. 2021.Improving Indoor Air Quality by Using SheepWool Thermal Insulation. Materials 14, 2443, https://doi.org/10.3390/ma14092443

Korniłłowicz-Kowalska, T., Bohacz, J., 2011. Biodegradation of keratin waste: Theory and practical aspects., Waste Management 31 (8), 1689–1701, https://doi.org/10.1016/j.wasman.2011.03.024

Mansour, E., Curling, S., Stéphan, A., Ormondroyd, G.,2016. Absorption of volatile organic compounds by different wool types, Green Materials 4 (1), 1-7, https://doi.org/10.1680/jgrma.15.00031

Ormondroyd, G.A., Curling, S.F., Mansour, E., Hill, C.A.S., 2017. The water vapour sorption characteristics and kinetics of different wool types, Journal of the Textile Institute 108 (7), 1198-1210, https://doi.org/10.1080/00405000.2016.1224442.

Patnaik, A., Mvubu, M., Muniyasamy, S., Botha, A., Anandjiwala, R. D., 2015. Thermal and sound insulation materials from waste wool and recycled polyester fibers and their biodegradation studies, Energy and Buildings 92, 161-169, https://doi.org/10.1016/j.enbuild.2015.01.056

Regulation (EC) No 1069/2009 of the European Parliament and of the Council of 21 October 2009

Sigaard, A.S.; Løvbak Berg, L.; Klepp, I.G., 2022. WOOLUME: Potential New Products from Vacant Wool; SIFO Report No. 18-2021; OsloMet: Oslo, Norway

Wheat bran proteins – raw material for production of nutritional-valued food

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Keywords: Wheat bran, wheat bran proteins, high protein food

ABSTRACT

Wheat bran (WB) is a sustainable material produced by milling industry in very high quantities. It forms cover layers of wheat kernel, which are removed during wheat flour production. This secondary product contains many nutritional significant components, which could be utilized for the enhancing the food quality. The protein fraction is one of the most abundant components of wheat bran (13–18 %) and according to its nutritional characteristics, the inclusion to human diet seems to be convenient and required.

The proteins are the part of lignocellulosic structure of WB. However, it could be easily isolated thanks to its ampholytic nature by pH-shift method. The protein fraction is extracted by NaOH solution (pH 10 ± 0,1; 2 h; room temperature) in ratio 1:20 with continuous mixing. The proteins were separated from deproteined WB by centrifugation (8000 rcf, 15 min, r.t.) and precipitated by pH adjustment to 4 ± 0,05 (1M citric acid). Precipitated proteins were isolated by centrifugation and dried by lyophilization.

The quality proteins are nutritionally very significant commodity which is recommended to be a common part of a diet, especially for the athletes and the elderly. WBPI contains more than 80 % of proteins represented by several protein fractions (up to 170 kDa). As it is typical for plant proteins, the most abundant amino acid of WBPI is glutamic acid. However, there are also high concentrations of amino acids, which are helpful in muscle and wound regeneration, as arginine and proline. This protein isolate seems to be ‘complete’ according to the representation of all essential amino acid. The limiting amino acids of WBPI are phenylalanine and tyrosine. However, the determined 93% digestibility of this material provides the opportunity for utilization of WBPI in production of food with added nutritional value.

As the part of this research, WBPI was used for production of several food commodities with added protein value, e. g. baguettes, yogurt, or bars. In all these products the protein content was increased by the addition of WBPI which made them high-protein food. However, during the production it was necessary to reflect the negative side effects of WBPI addition to different food matrices. The defects of products were evaluated by rheological (product fragility/rigidity) or sensory analysis (acidity/bitterness of WBPI) and eliminated by different approaches (change of recipe procedure, flavour masking, etc.).

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References:

Balandán-Quintana, R. R., Mercado-Ruiz, J. N., Mendoza-Wilson, A. M. (2015). Wheat Bran Proteins: A Review of Their Uses and Potential. Food Reviews International, 31(3), 279-29, https://doi.org/10.1080/87559129.2015.1015137.

Application of sheep wool as slowly released organic fertilizer in tomato and winter wheat cultivation

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Keywords: sheep wool, waste, wool biodegradation, organic fertilizer, nitrogen supply

ABSTRACT

For many years, sheep wool was used as a precious raw material used for the production of apparel textiles, carpets and blankets. In recent decades, due to the rapid development of products made from synthetic fibres, the demand for wool has declined significantly and the share of wool in global fibre production has decreased considerably. At the same time, wool has lost its economic value and the costs of sheep shearing have overweighed the price of the material. In many countries, sheep husbandry was reoriented on meat production, while wool became a worthless and troublemaking by-product. The deep crisis affected especially coarse wool obtained from local breeds, including breeds raised traditionally in mountain areas.

To find a reasonable solution for the utilization of wool surpluses, several attempts of using it as a soil amendment and organic fertilizer in agricultural and horticultural crops were undertaken (Zheljazkov et al. 2009; Abdallah et al. 2019a). As a protein fibre, wool is composed of carbon, nitrogen and sulphur, elements that play an essential role in plant development. It undergoes biodegradation, resulting in nitrogen-rich organic compounds being gradually released into the soil. Then, the compounds undergo ammonification and nitrification, whereby organic nitrogen is transformed into ammonium and nitrate forms making the keratin resource become available and accessible for plant nutrition (Broda and Gawlowski 2018). In addition to nutrition function, wool mixed with soil retains water and improves several soil's physical properties (Abdallah et al. 2019b; Broda et al. 2020). The positive impact of wool on plant growth was repeatedly shown in the cultivation of cereals and various vegetables (Lal et al. 2020; Bohme 2021).

To maximize the valorisation of wool obtained from sheep raised in Polish mountains, investigations on its application as a fertilizer in tomato and winter wheat cultivations were performed. For the purpose of the research, waste wool left after the selection of better quality material designed for spinning of rug yarns was separated right after sheep shearing. The waste included partially felted wool, fibres contaminated with faces or mud and short wool sheared from sheep legs, tails and heads.

Before the field tests, raw, unwashed and naturally contaminated waste wool was examined. During these examinations, heavy metal concentration and polycyclic aromatic hydrocarbons content were determined. It was revealed that the fibres do not contain any excess heavy metals and residues of other harmful substances. It was concluded that this wool can be safely applied as a clean soil additive and its application does not involve any risk of soil contamination (Broda et al. in press).

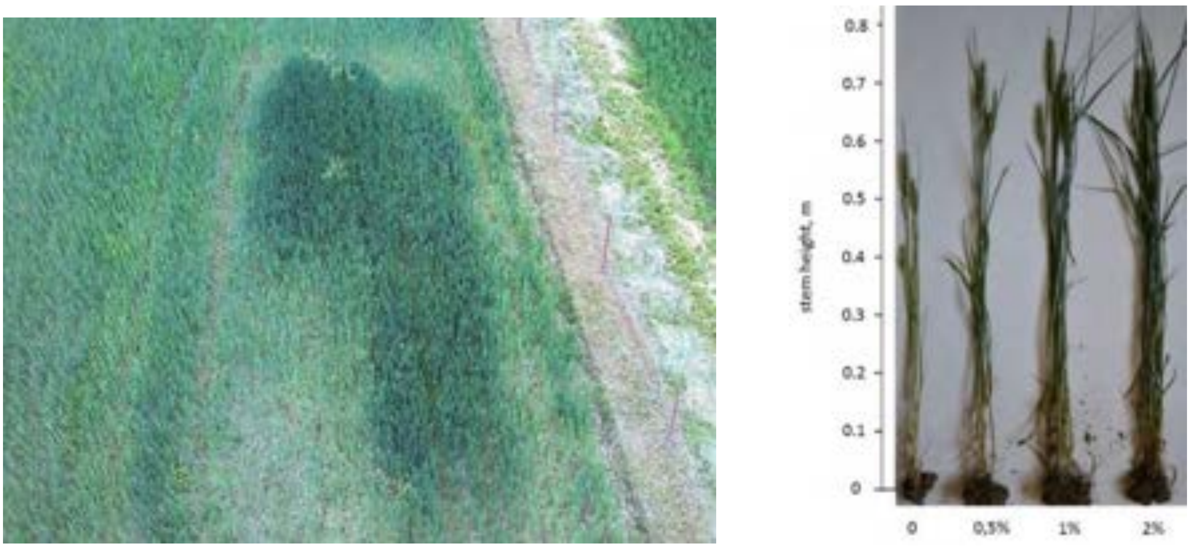
The waste wool containing grease and other natural contaminants was cut with a prototype cutting device into short, few-millimetre-long segments. Its fertilizing efficiency was then examined in experimental plots.

The studies on tomato growth were carried out inside a foil tunnel. The cut wool was spread on the soil surface in the amount of 0.5 and 1% in relation to the weight of the 20 cm layer of soil. Then, the wool was covered with a thin layer of soil in which tomato seedlings were planted. During vegetation, the growth of the plants was monitored. At the harvest, the size of tomatoes was measured and their yield was determined. It was found that the average size of tomatoes grown in plots fed with wool is much larger and their yield is twice as large (Figure 1).

a/ b/

Figure 1. A tomato grown in soil fertilized with wool by different amounts of wool; a/ 0.5%; b/ 1%.

The studies on winter wheat were conducted in a field with arable soil of average quality. In the experimental plots, different amounts of cut wool (0.5%, 1% and 2%) in relation to the weight of the 20 cm layer of soil were spread out on the field surface and mixed with soil with a rotary tiller. In autumn, the field was sown with winter wheat. Next year, throughout the vegetation period, the wheat growth was systematically monitored, while the tillering degree, height of stems and colour of leaves were assessed. At the harvest, the yield of wheat was determined.



a/ b/

Figure 2. Winter wheat grown on soil fertilized with wool; a/ overview of the field with experimental plots fertilized with wool during stem elongation stage; b/ wheat steams grown in experimental plots by different wool amounts

It was revealed that thanks to the addition of wool, the tillering degree of wheat was almost two times higher. During the stem growth stage, the wheat had intensive dark green colour and its blades were considerably higher (Figure 2). Finally, the wheat yield from the plots fertilized with wool was much bigger. A significant increase in the yield was observed already at a small amount of wool added. At higher wool doses (1 and 2%), the yield is much bigger, reaching twice the level obtained for plots containing no fertilizer.

During wheat growth, the progress of wool biodegradation in natural conditions in the soil was monitored. It was stated that cutting results in mechanical damage of wool. Due to the damage of the outer cuticle layer, the natural enzymatic resistance of wool is weakened and enzymes released by microorganisms naturally present in the soil have easier access to the fibres. As a result, the biodegradation of cut wool is initiated quickly and proceeds successively for several months.

During biodegradation, the compact wool's keratin structure is gradually broken down, while nitrogen-rich peptides and particular amino acids are released into the soil. In experiments during wheat growth, the content of the organic and mineral forms of nitrogen in the soil was controlled. It was revealed that the nitrogen supply is strictly correlated with the progress of wool biodegradation.

The analyses of the results of performed studies led to a conclusion that raw waste wool can be used as an environmentally friendly organic fertilizer with high nitrogen content (several times higher than in other organic fertilizers). Useless, waste wool obtained just after sheep shearing, not submitted to any additional chemical and environmentally unfriendly treatment can be safely applied as such fertilizer. The preferable form of fertilizer are fibres cut into short segments. The cut wool can be easily compounded with the soil using agricultural machinery. The cut wool is more easily biodegradable and ensures nitrogen supply shortly after planting seedlings or seeding. Then, contrary to conventional mineral fertilizers, the nutrients are systematically delivered to plants during the whole vegetation season. With an appropriate dose of wool, nitrogen is available to plants in sufficient quantities in successive stages of their growth. Since the biodegradation of wool does not end with the vegetation season, the supply of nitrogen is ensured until the last stage of growth. The systematic supply of nitrogen during all growth stages ensures a high yield. Slow release of nitrogen and its successive consumption during plant growth enables better nutrient utilization and reduces losses of nitrogen through volatilization, leaching and denitrification. Proper timing is also favourable to the environment and protects water resources from contamination resulting from excessive nitrogen release.

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References:

Abdallah, A.M., Ugolini, F., Baronti, S., Maienza, A., Ungaro, F., Camilli, F., 2019. Assessment of Two Sheep Wool Residues from Textile Industry as Organic Fertilizer in Sunflower and Maize Cultivation. J Soil Sci Plant Nutr 19. https://doi.org/10.1007/s42729-019-00079-y

Abdallah, A., Ugolini, F., Baronti, S., Maienza, A., Camilli, F., Bonora, L., Martelli, F., Primicerio, J., Ungaro, F., 2019. The potential of recycling wool residues as an amendment for enhancing the physical and hydraulic properties of a sandy loam soil. International Journal of Recycling of Organic Waste in Agriculture 8. https://doi.org/10.1007/s40093-019-0283-5

Böhme, M.H., 2021. Organic sources of nutrient supply for tomatoes and Asian herbaceous vegetables in soilless culture systems. Acta Hortic 1321. https://doi.org/10.17660/ActaHortic.2021.1321.20

Broda, J., Gawlowski, A., 2018. Influence of Sheep Wool on Slope Greening. Journal of Natural Fibers 1–13. https://doi.org/10.1080/15440478.2018.1534190

Broda, J., Mitka, A., Gawłowski, A., 2020. Greening of road slope reinforced with wool fibres. Mater Today Proc. https://doi.org/10.1016/j.matpr.2020.01.249

Broda, J., Gawlowski, A., Rom, M., Kobiela-Mendrek, K. 2023. Utilisation of waste wool from mountain sheep as fertilizer in winter wheat cultivation. Journal of Natural Fibers, in press

Lal, B., Sharma, S.C., Meena, R.L., Sarkar, S., Sahoo, A., Balai, R.C., Gautam, P., Meena, B.P., 2020. Utilization of byproducts of sheep farming as organic fertilizer for improving soil health and productivity of barley forage. J Environ Manage 269. https://doi.org/10.1016/j.jenvman.2020.110765

Zheljazkov, V.D., Stratton, G.W., Pincock, J., Butler, S., Jeliazkova, E.A., Nedkov, N.K., Gerard, P.D., 2009. Wool-waste as organic nutrient source for container-grown plants. Waste Management 29. https://doi.org/10.1016/j.wasman.2009.03.009

Integrated Chemicals and Waste Management for Reduction of Adverse Effects to Environment

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ABSTRACT

Over the last decades the rapid growth in chemicals production and trade has caused concerns among the international community about the possible risk associated with the use of hazardous chemicals and pesticides. Countries that have no necessary infrastructure in place to monitor and control the import and use of these substances are particularly vulnerable in this regards.

Since the use of chemicals has become an important means of achieving success in the economic and social development of countries, it is necessary to maximize benefits of chemicals use of and minimize their adverse effects on human health and the environment. In this regard, the development of legislative and technical infrastructure for the safe production and handling of chemicals, as well as ensuring their proper use, is extremely important.

In the Republic of Armenia the key direction of State policy in the area of nature protection is ensuring sound management of chemicals and wastes in order to prevent their harmful impacts towards the environment and human health.

Issues related to environmental and human health protection are included in all strategy documents of the country.

Chemicals and wastes management in Armenia is based on development and implementation of integrated approach aimed at efficient arrangement of chemicals safe production and application, as well as prevention of their harmful impacts to human health and ensuring healthy environment.

The integrated approach in the area of chemicals and wastes management presupposes creation, strengthening of cooperation at the national level between ministries, research and academy institutions, industrial associations, NGOs. This is the platform for efficient and coordinated actions for consideration of national priorities in the area of chemicals and wastes management, as well as for effective implementation of international agreements and initiatives related to chemicals and wastes.

Currently there is no Law “On Chemicals” in Armenia. In the Republic of Armenia chemicals and wastes management is implemented under Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, Stockholm Convention on Persistent Organic Pollutants and Minamata Convention on Mercury.

In order to carry out obligations undertaken within the ratified conventions the “List of hazardous wastes prohibited for import to/ export from the Republic of Armenia”, “List of prohibited industrial chemicals and wastes regulated under the Stockholm and Rotterdam Conventions, as well as “List of mercury containing products” , the ban on their production, import, export were approved.

For sound management of chemicals in the Republic of Armenia the following is required:

- establishment of a unified system for chemicals registration

- setting forth requirements on chemicals classification,
- setting forth requirement for chemicals labelling that will ensure efficient system for notification of the final consumer about the hazardous properties of chemicals
- integrated regulation of chemicals import and export system establishing and clearly differentiating authorities/ responsibilities of state governance bodies in the area of chemicals handling
- establishing the rights and responsibilities of persons involved in the chemicals handling area,
- setting forth responsibility for violation of legislative requirements on chemicals handling;
- Chemicals Registry development, and
- registration of chemicals importers and manufacturers and the chemicals they offer on the market for professional use and for use among the general public.

The information about importers and manufacturers of chemicals and the market for chemicals in the country is needed. It is crucial to develop contacts with them and the dialogue for the implementation of this roadmap.

It is necessary to have statistics about chemicals in the country, composition, use of substances in chemicals, the aim of each chemical, changes in use patterns.

Considering principles of Chemicals Health and Safety at the work places, it is necessary to strengthen the prevention of risks by eliminating the sources of risks, change the choice and use of chemicals and chemical-technical solutions, by collective measures and organizational changes in the work environment.

Ensuring the process of providing information related to health impacts of chemical factors, including different type produce, natural poisons, industrial chemicals, pesticides, their hazards, chemical and toxicological properties, antidotes and treatment; integration in the international chemical information network.

References:

Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal

Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade

Stockholm Convention on Persistent Organic Pollutants

Minamata Convention on Mercury.

Session B4: Urban and regenerative agriculture

Urban agriculture in Latvia – is that a choice between business, community networking and individual traditions?

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Keywords: urban agriculture, Latvia, sustainable cities

ABSTRACT

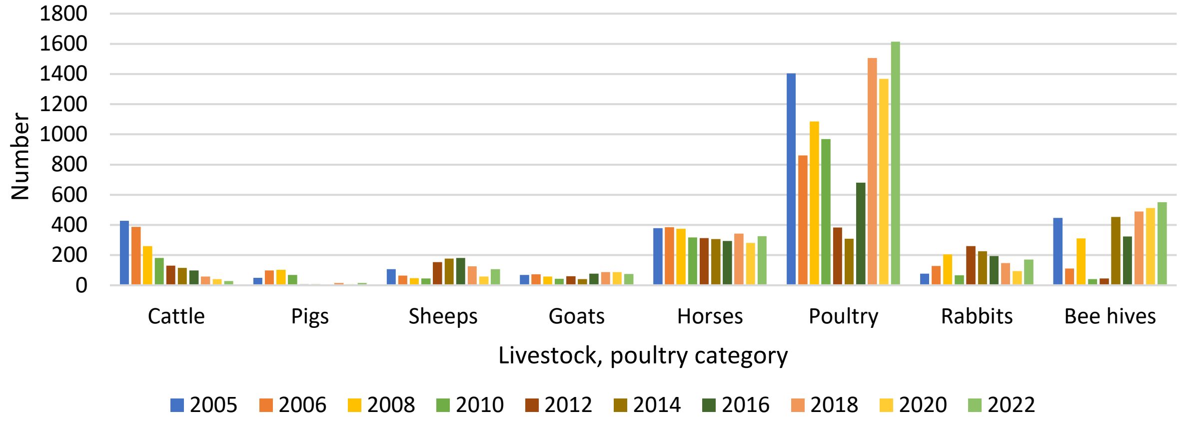
The society of the 21st century faces and is aware of a wide range of sustainability challenges. From the crisis of social cohesion to adverse climate changes, the multifaceted nature of risks makes it necessary to look for systemic solutions that would not only reduce the impact of risks, but also change of society's values. Therefore, the sustainability of all dimensions of the urban environment is one of the development criteria on a global scale. The increasing intensity and risks of urbanization challenge the possibilities of urban regeneration. The topicality of urban regeneration creates the need to reassess existing development trends and the systems of social interaction, resource consumption and value understanding contained in them.

Agriculture is a primary sector that provides not only the primary needs of society, but also creates awareness of food resources, process and system at different levels and groups of society. Agricultural practice in the urban environment in the 21st century has acquired a historically new and unprecedented multifunctionality. Taking into account the change of functions of urban agriculture, when it was initially the basic principle of urban planning, but then with the period of the Industrial Revolution it was conceptually separated from the urban environment, the multifunctionality of the practice realized in the 21st century allows to identify its renaissance period (Dobele & Zvirbule, 2020). Urban agriculture covers a wide range of functions, from providing food resources and promoting urban sustainability, to developing education and innovation and building social cohesion (Dobele, Dobele & Zvirbule, 2022). Food growing and agriculture in the 21st century is mostly associated with rural areas, their characteristic way of life and aspects (Nowysz et al., 2022). Therefore, the conceptualization of urban agriculture is related not only to food production as the basic function of the practice, but to a much wider range of functions specific to the urban environment. Although urban agriculture is often defined broadly and simplistically as the cultivation of plants and livestock within the boundaries of the city (Caldas, Christopoulos, 2023), in the understanding of urban agriculture, the essential aspect is that agriculture in cities is much more closely integrated into urban systems, space and environment than agriculture in the territories of the countryside (Tóth, Timpe, 2017).

Also in Latvia, urban agriculture is a multifunctional practice, but the functionality is affected by several specific aspects. Agriculture is a cultural-historical activity of Latvian society, but the increase in the level of life quality reduces the economic motivation of the practice. Food growing traditions in Latvia are old and socially supported, however, urban agriculture as an activity promoting and supporting the sustainability of cities is relatively underdeveloped both in practical implementation and research. Therefore, in this study, the analysis of urban agriculture in Latvia includes the characterization of three directions: urban agriculture as a household self-consumption practice, as a social community initiative and as a commercial activity. In the study, the demarcation of the "urban" environment is subordinated to the 10 State cities of Latvia. "Agriculture" is conceptualized as the economic activity of crop cultivation and animal husbandry.

In Latvia, the **commercial trends** of urban agriculture are difficult to analyse. The Central Statistical Bureau compiles statistics on industry companies registered in the State cities. However, the data are not unambiguously applicable to the practice of urban agriculture, taking into account that the place of company registration and practice often differ. And even then, only 6% of the entire country's agricultural sector enterprises are registered in State cities, which proves the lack of interest in commercial practice in urban agriculture (Tirgus sektora ekonomiski…, (n.d.)). The areas of agricultural land in State cities are also

small - in 2022, the area of agricultural land in the cities is 1,617 ha and constitutes 0.03% of the total territory of the country and 0.07% of the total area of agricultural land, which indicates the focus of the use of land resources on non-agricultural land in the cities (Land distribution land..., 2020). The relatively large proportion of meadows and pastures in the agricultural lands of the State cities may indicate the potential for livestock and poultry farming practices, however, the number of livestock and poultry does not confirm this (Figure 1).



Source: author's construction based on Lauksaimniecības datu centrs, (n.d.)

Fig.1. *Number of livestock and poultry in State cities at the beginning of the year 2005-2022 in Latvia.*

Trends in the number of livestock and poultry in Latvian cities are fluctuating - only in such categories of livestock as cattle and pigs is there a decrease in the number. The consumption of beef and pork among city residents is also decreasing (Pārtikas produktu patēriņš vidēji..., (n.d.)), therefore, the decrease in the number of these livestock is not related to the decrease in the relevance of urban agriculture. The increasing trends in numbers in categories such as poultry and bee hives indicate a reorientation of urban agriculture to those groups of livestock and poultry that are relatively easier to manage in household conditions. However, the overall trends in the number of livestock and poultry indicate that livestock farming currently is not the primary direction of agriculture in Latvian cities, taking into account that both the number and the proportion of animals are decreasing in almost all livestock farming groups.

Analysing the case study of the commercial activity of urban agriculture in Latvia (Dobele, 2022), it can be concluded that urban agriculture is primarily a complementary practice. "Hotel Janne" Ltd, which operates in the field of guest accommodation, has also established an urban beehive on the company's territory since 2018. Company owner and beekeeper Valdis Janovs admits that the primary function of urban agriculture in his company and the choice to create an apiary in the capital is related to restoring the connection between nature and human, diversifying the urban environment and popularizing green lifestyle and thinking. The analysis of urban agriculture practice in "Hotel Janne" Ltd concludes that the urban environment is conducive to beekeeping, as the main challenges are related to increased risks of vandalism and theft, but the environment, the availability of multiflora, the non-use of agricultural chemicals in cities and the proximity of educational institutions are contributory aspects in the implementation of the practice. In addition, currently urban agriculture in Latvia has a good potential for the development of tourism, taking into account that the practice of commercial activity is not yet widely developed. However, the existing business trends, which also include a relatively lower average wage in the agricultural sector compared to other sectors, a high level of the employment in the State cities and high costs of land resources, are hindered economic factors (Dobele et al., 2022).

Urban **community gardens** have a high potential for building community ties, as they are characterized by a collective management and use of production, often as an initiative to reduce social and economic risks in the community (Nowysz et al., 2022). That is why community gardens have the potential of several, especially social, functions - they support community formation, socialization, have educational and recreational functions (Trendov, 2018). Determining the trends of community gardens in the Latvian situation is complicated by the fact that community gardens in Latvia are mostly registered as associations whose activities are not directly related to agriculture. Therefore, identifying the number, proportion and scope of practice of community gardens in Latvia is only possible based on the principles of case study selection. The practice of community gardens is not widely developed in Latvia - there are several community gardens in the capital, but only a few in other cities. Most of the activities of community gardens are related to horticulture and its financial base is made up of donations, membership fees or fundraising from environmental and educational projects (Dobele, 2022). However, community gardens in Latvia are currently not supported by local governments, which make their development fragmentary and without systematic support and evaluation in the sustainable development of the State cities.

Urban agriculture is able to create links between urban and rural environments, food production and consumption, nature and culture, people and places, both at the macro level through community and social initiatives, and at the micro level in individual habits and households (Wittenberg et al., 2022). Therefore, in the analysis of urban agriculture practices and its functions, it is important to evaluate not only commercial practices and community activities, but also individual, **household activities** that ensure social sustainability at the individual, household level. In order to identify the habits of Latvian households in the context of urban agriculture, in 2021 a survey of the residents of Latvian State cities was conducted, in which 620 respondents participated. 65% (n=406) of the State cities' residents grow at least one food product in their household, which shows that food growing in the urban environment is widely developed. However, the results of the survey show that urban agriculture in Latvia is mostly practiced in the form of micro-agriculture (Table 1).

Table 1: Indicators characterizing the practice of urban agriculture in the population survey

Duration of experience, years		**Time spent on practice, h avg. week**		**Amount of grown production in consumption, %**		**Types of products**	
category	resp., %	category	resp., %	category	resp., %	category	resp., %
up to 1	12	up to 2	61	up to 10	56	herbs	94
1-2	20	2-4	24	11-25	15	vegetables	64
3-5	28	5-7	7	26-35	14	fruit trees, berry bushes	46
6-10	14	8-10	4	36-50	10	berries	40
more than 10	26	more than 10	4	51-74	3	poultry for meat, eggs	8
				more than 75	2	livestock	2

Source: author's construction based on the results of a survey of respondents (n=406)

The approach of micro-agriculture is evidenced by several aspects of practice: 1) *very short time is consumed for practice* (61% of respondents spend up to 2 hours per week on average for agricultural practice); 2) *the proportion of the grown production in the volume of household consumption in the relevant product group is small* (56% of respondents grow only up to 10% of the necessary food); 3*) goals of growing food* (78% of Latvian respondents grow food for household consumption, 19% both for self-consumption and for giving to family and friends, only 2.5% also for sale); 4) *the most frequently grown types of products* (herbs, which are a relatively less time and labour-intensive group, are grown by 94% of respondents). Although the volumes of household practice are small, practicing urban agriculture is an essential part of the daily life of residents in the urban environment. The results of the survey show that residents are primarily motivated by the opportunity to green their surroundings (77% of practitioners this is an important motivator), which interacts with the environmental dimension of urban sustainability. Also, the implementation of the practice is motivated by aspects related to education: 70% of respondents choose urban agriculture as a household practice motivated by the opportunity to learn something new, and more than 90% of respondents evaluate it as a practice that potentially could complement the educational program. The high functionality of educational promotion in the context of Latvian urban agriculture is also indicated by experts, emphasizing that practice promotes the acquisition of knowledge, regardless of its scope and place of implementation (Dobele, Dobele & Zvirbule, 2023).

Urban agriculture in Latvia is closely related to cultural-historical traditions. For 76% of practitioners, the important motivator is the tradition of growing food in the family. In addition, 73% of practitioners acquire knowledge about agriculture from their family. This proves that growing food is a traditional activity also among the residents of Latvian State cities and promotes the development of the practice. However, the residents are not motivated by the potential of the practice to create opportunities for socialization with others (only 15% of respondents state this as an important motivator). This aspect also interacts with the relatively small number of community gardens in Latvia, which shows that residents currently do not value urban agriculture as an aspect promoting social cohesion. At the household level, as well as in the approach of commercial activities and community gardens, residents evaluate urban agriculture as a resource-intensive practice (only 28% of respondents admit that the value of the food grown covers the resources consumed in its cultivation, 47% answered that partially and 25% denied). This shows that the development of urban agriculture in Latvia in all approaches (business, community networking and individual traditions) should primarily be based on social and environmental functions and motivational aspects.

Evaluating the existing trends of urban agriculture in Latvia, it can be concluded that the practice is currently mostly implemented at the household level. However, given the multifunctionality potential of urban agriculture in promoting urban sustainability, it should not be an exclusive choice between different directions of implementation of the practice. In order for urban agriculture in Latvia to function as a practice integrated into urban systems for sustainable cities, it is necessary to develop and promote community activities and commercial practices as well. The attitude and habits of the population are conducive to the practice, therefore the inclusion of urban agriculture in the form of community gardens in the planning of the territories of the State cities and the development of support systems for the promotion of commercial activity would provide a basis for the development of urban agriculture as a factor contributing to the sustainability of cities in Latvia.

References:

Caldas L.C., Christopoulos T.P., 2023. Social capital in urban agriculture initiatives. Revista de Gestao, 30 (1), 92-105, https://doi.org/10.1108/REGE-03-2021-0043.

Dobele, M., 2022. Economic and social aspects of urban agriculture in Latvia - a case study. Journal of Regional Economic and Social Development, 14, 29-41, https://doi.org/10.17770/jresd2022vol14.6965.

Dobele, M., Dobele A., Zvirbule A., 2022. Multifunctionality of urban agriculture and its characteristics in Latvia. Rural Sustainability Research: Scientific Journal of Latvia University of Life Sciences and Technologies, 48 (348), 54-67, https://doi.org/10.2478/plua-2022-0016.

Dobele, M., Zvirbule, A., 2020. The concept of urban agriculture – historical development and tendencies. Rural Sustainability Research, 43 (338), 20-26, https://doi.org/10.2478/plua-2020-0003.

Dobele, M., Zvirbule A., Dobele A., Muska A., 2022. Factors affecting the development of urban agriculture in Latvia. Research for Rural Development 2022: annual 28th International scientific conference proceedings, 37, 158-165, https://doi.org/10.22616/rrd.28.2022.023.

Lauksaimniecības datu centrs. (n.d.) Retrieved January 5, 2023, from: http://pub.ldc.gov.lv/pub_stat.php?lang=lv.

Nowysz A., Mazur Ł., Vaverková M.D., Koda E., Winkler J., 2022. Urban Agriculture as an Alternative Source for Food and Water Security in Today's Sustainable Cities. International Journal of Environmental Research and Public Health, 19 (23), Art. 15597. https://doi.org/10.3390/ijerph192315597.

Pārtikas produktu patēriņš vidēji uz vienu mājsaimniecības locekli gadā (kg gadā, ja citādāk – norādīts īpaši), (ECOICOP) 2015-2019. (n.d.) Retrieved May 19, 2023 from: https://data.stat.gov.lv/pxweb/lv/OSP_PUB/START__POP__MB__MBP/MBP010/.

Tirgus sektora ekonomiski aktīvi uzņēmumi reģionos, republikas pilsētās un novados sadalījumā pa uzņēmumu lieluma grupām pēc nodarbināto skaita un galvenajiem darbības veidiem (NACE 2.red.) 2013-2020. (n.d.) Retrieved March 3, 2023 from: https://data.stat.gov.lv/pxweb/lv/OSP_PUB/START__ENT__UZ__UZS/UZS030/.

Tóth A., Timpe A., 2017. Exploring urban agriculture as a component of multifunctional green infrastructure: Application of figure-ground plans as a spatial analysis tool. Moravian geographical reports, 25 (3), 208-218, https://doi.org/10.1515/mgr-2017-0018.

Trendov N.M., 2018. Comparative study on the motivations that drive urban community gardens in Central Eastern Europe. Annals of Agrarian science, 16, 85-89, https://doi.org/10.1016/j.aasci.2017.10.003.

Zemes sadalījums zemes lietošanas veidos, 2020. Retrieved January 5, 2023 from: https://www.vzd.gov.lv/lv/zemes-sadalijums-zemes-lietosanas-veidos.

Linking Nature, Culture, and Food as an Urban Farming Nature-based Solution

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Keywords: Zone Sensible, Biodiversity, Climate change, Food security, Economic and Social Development, Human Health.

ABSTRACT

The H LAB project, initiated in 2020, is a one-hectare laboratory that conducts action-research in collaboration with the artistic collective Parti Poétique and the Zone Sensible site. It aims to understand the social and ecological benefits of conserving one hectare of agricultural land in a densely urbanized area. Zone Sensible, managed by Parti Poétique, is a model of harmonious integration between nature and the city. The project, developed over a 24-month rehabilitation period, reactivates the land while preserving its nourishing qualities and introducing new uses for the public, researchers, artists, and urban agriculture actors. The permaculture approach adopted by Parti Poétique ensures long-term respect for ecosystems and low-carbon sustainable agriculture.

Zone Sensible serves as an educational platform, organizing guided tours, workshops, conferences, and events to engage the public and raise awareness about environmental and social issues. It is an urban farm project in Porte de Paris à Saint-Denis that preserves a unique heritage site and contributes to hyper-local agricultural and food production. It was identified as UNESCO Green Citizen in 2019.

The site incorporates sustainable installations like gardens, greenhouses, beehives, shared workspaces, and exhibition areas, fostering collaboration and collective learning among artists, researchers, gardeners, and residents.

Overall, the H LAB project and Zone Sensible exemplify the fusion of art, research, and sustainable practices to explore new forms of cohabitation and co-creation between humans and their environment, while promoting biodiversity, urban agriculture, ecology, and citizen participation.

To achieve the goal of demonstrating the added value of Zone Sensible, an approach to explore is to align it with the conceptual framework of Nature-based Solutions (NbS) developed by the International Union for Conservation of Nature (IUCN). By doing so, Zone Sensible can benefit from the established criteria and indicators of NbS to showcase its effectiveness and contributions in addressing global challenges. Nature-based Solutions are actions that utilize ecosystems to address societal issues while ensuring human well-being and biodiversity benefits. The NbS standard consists of eight criteria and 28 indicators, which can be utilized to assess the extent to which Zone Sensible embodies the characteristics of a Nature-based Solution. This alignment with NbS could expand the project's visibility, strengthens its credibility, and unlocks additional financial opportunities.

The spider chart (Figure 1) represents the performance or achievement levels of each criterion. The criteria are plotted as points on the chart, and the percentage values indicate the level of accomplishment for each criterion.

For example, C1 (Societal Challenges) has a result of 78%, indicating a relatively high level of success in addressing and tackling societal challenges. On the other hand, C3 (Biodiversity Net-Gain) has a result of 50%, suggesting that there may be room for improvement in achieving net gains in biodiversity.

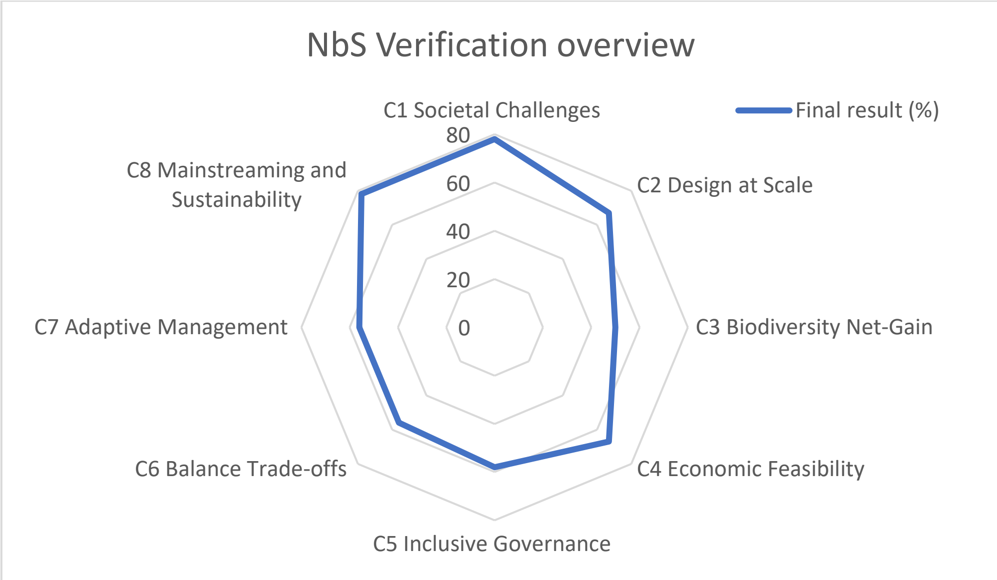

Figure 1. Percentage assessment of NbS criteria

In conclusion, this study shows that the urban farm Zone Sensible performs well for the criteria and could certified as Nature based Solution according to the IUCN standard for NbS. This could be a pioneering analysis to be applied to other urban farm projects to increase their visibility and impact.

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References:

CICES Common international classification of ecosystem services. 2023. Towards a common classification of ecosystem services. Retrieved from https://cices.eu/cices-structure/

IUCN International Union for Conservation of Nature. (2016). Nature-based Solutions to address global societal challenges. In: Cohen-Shacham, E., Walters, G., Janzen, C. and Maginnis, S. (eds.) Gland, Switzerland: IUCN. 97pp. http://dx.doi.org/10.2305/IUCN.CH.2016.13.en

Partie Poetique. (2017-2018). Rapport d'activité. Saint-Denis, France.

Partie Poetique. (2019). Rapport d'activité. Saint-Denis, France.

Partie Poetique. (2020). Rapport d'activité. Saint-Denis, France.

Partie Poetique. (2021). Rapport d'activité. Saint-Denis, France.

Partie Poetique. (2022). Rapport d'activité. Saint-Denis, France.

UICN Union Internationale pour la Conservation de la Nature. (2020). Standard mondial de l'UICN pour les solutions fondées sur la nature. Cadre accessible pour la vérification, la conception et la mise à l'échelle des SfN. Première édition. Gland, Suisse : UICN. https://doi.org/10.2305/IUCN.CH.2020.08.fr

UNESCO. (2023). Green Citizens. Retrieved from https://www.unesco.org/en/green-citizens

HABSIM – Unique R&D Infrastructure for closed-loop food production in space and on Earth

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Keywords Space, Bioeconomy, Closed-loop, Food, Post-harvest management, Moon

ABSTRACT

There is a reinvigoration of human space travel and the goal is to establish a moon base with a constant human presence by 2030 to eventually bring mankind to Mars. Missions to the Moon come with a myriad of challenges and even though we may have the required technology to bring humans to the Moon, we do not have the food system to sustain them. Ultimately food is a limiting factor for human space travel. Due to resource and cost limitations and food acceptability challenges, future lunar habitats cannot rely solely on resupply missions from Earth. As a result, in situ food production becomes a necessity for sustained human space travel.

There is a variety of research on how to provide food for space missions, such as insect farming, cultivated meat and Controlled Environmental Agriculture (CEA) where projects such as the EDEN ISS developed by the German Aerospace Centre (DLR), have shown promise in closed-loop food production during space analog missions. However, there are still certain gaps to be addressed if food production on the moon is ever to become truly independent, variable and nutritionally adequate. For instance, certain areas such as nutrient rich crop production, and post-harvest management including food storage and food processing have been overlooked.

Food processing will not only extend shelf life and increase the nutritional qualities of certain foods, but also create new products, and introduce new crop varieties e.g., staple foods such as cereals and tubers. Similarly, alternative sources of protein such as cultivated meat and insects needs processing, preparation and storage to be acceptable. Subsequently leading to a highly sufficient and variable diet over the long run. Furthermore, food processing may lead to better caretaking of side streams from the greenhouse or crew waste, which in turn can be refined into useful products that promote the circularity of the closed-loop habitat.

In current landscape of space food research, the efforts are scattered and lack a cohesive, integrated approach. A holistic multi-factored approach to test the synergies between different innovations as well as with humans in the loop, is a requisite to accelerate current food production research and innovations. Existing research initiatives and facilities often focus on isolated aspects of space food production, failing to address the critical need for a holistic understanding of the synergies between different innovations and the inclusion of human factors. To address this, a centralized facility is needed to serve as a hub, bringing together diverse research and innovations under one roof. Such a facility would provide a unique opportunity to systematically test and evaluate the interplay between various space food research components, while incorporating the invaluable insights gained from human involvement. By bridging the existing gaps and fostering collaboration, this comprehensive platform would accelerate the pace of research and implementation in space food production, ultimately advancing the prospects of sustainable food systems for future space missions.

The objective of this project is to establish a centralized facility that integrates post-harvest management and Controlled Environmental Agriculture (CEA) systems, bolstered by state-of-the-art laboratory infrastructure. This facility aims to serve as a versatile closed loop food production system, specifically designed for future lunar habitats, allowing for comprehensive testing and acceleration of any related research.

The urgency behind this endeavor stems from the current roadmaps of international space agencies are to establish a constant human presence on the Moon before the end of the decade. By developing this research facility, we aim to address the critical need for advanced food production capabilities that will support prolonged lunar missions, laying the foundation for sustainable food systems in extraterrestrial

and terrestrial environments. This comprehensive platform will foster collaboration, bridge existing gaps, and accelerate the pace of research and implementation in space food production, ultimately advancing the prospects of sustainable food systems for future space missions and on Earth.

The HABSIM project team aims to create a comprehensive concept for a world-class research infrastructure in the area of sustainable closed loop food production and management, using space as a testing ground to foster out-of-the-box thinking. The plan is to establish an international incubator that focuses on accelerating and testing the synergies between food pre-harvest and post-harvest technologies, as well as the utilization of inedible biomass and bio-based materials for manufacturing. This initiative aims to develop innovative food production solutions for space infrastructures, while also fostering sustainable applications for terrestrial markets. The HABSIM is designed with circularity in mind, aiming to recycle and reuse water, heat, and gas, and utilize side stream and biowaste processing for nutrient reintroduction and natural product extractions. The goal is to achieve complete self-sufficiency in consumable materials, including packaging, tableware, utensils, and nutrient components, all derived from the closed-loop system.

State of the art

The current roadmaps of international space agencies are to establish a human constant presence on the Moon by the end of the decade, to eventually bring humans to Mars (1). However, the lack of suitable food supplies poses a challenge, as food is a limiting factor for lunar habitats (2). Even though we may have the technology to bring humans to the Moon, we do not have the required food systems or the food technology to sustain them. Space food has evolved from toothpaste-like tubes to food similar to what we eat on Earth, emphasizing organoleptic appeal and variety to prevent menu fatigue. During longer missions, it is important to consider that food is not only a source of nutrients but should also ensure personal and emotional well-being. In other words, food plays an important role as a countermeasure to the many psychological challenges that humans experience on longer space missions (3). Nutrition is vital for overcoming physical challenges in deep space, as environmental conditions and reduced gravity impact the body's metabolic processes and the body’s nutrient utilization ability. Furthermore, microgravity affects pharmacokinetics and since research on pharmaceuticals and potential side effects in space is scarce, food is the primary source of nutrition and the most important countermeasure for these challenges (4) (5). Developing food for long space missions requires the consideration of these factors (6). Due to resource limitations and acceptability challenges, future lunar habitats cannot rely on Earth resupply missions, necessitating in situ food production (7). Greenhouse modules as an implementation into bio-regenerative life support systems (BLSS), such as the EDEN ISS project developed by the German Aerospace Centre (DLR), have shown promise in closed-loop food production during space analog missions (8). However, current space food and crop research are focused on fast growing ready-to-eat crops, which evolved as the main focus during the International Space Station (ISS) program to meet the immediate needs of astronauts in low Earth orbit. However, prior to the ISS program, the significance of staple foods like tubers and cereals was recognized as a vital part of an independent lunar food production system. Continuing previous research on staple foods in space is crucial for achieving an independent food production system. An area that has been overlooked in space food research is post-harvest management such as food storage and food processing, which is essential for meeting the aforementioned criteria, and a truly bio-regenerative and sustainable lunar food production made possible. Food processing can also facilitate the circularity of closed-loop habitats by utilizing side streams and waste. Additionally, a comprehensive approach is needed for testing synergies between different space food research and innovations, and involving humans in the loop for accelerated research and implementation.

Beyond state of the art

The current foods for space missions have limited shelf-life stability and rely on Earth-dependent pre-packed foods, which are not sustainable for longer interplanetary missions (9) (7). Existing research on space food production mainly focuses on pre-harvest technologies, such as micronutrient focused fast-growing crops, algae, insects and lab-grown meat. Areas such as post-harvest management has generally been overlooked, leaving a knowledge-gap of how to store and process food once its produced. Insects and meat all need processing and storage to be acceptable, while lunar greenhouses need to expand their crop selection to include staple foods that can be processed to provide a diverse and nutritious diet. To achieve this, post-harvest technologies such as food processing equipment and storage solutions must be implemented alongside greenhouse modules and other food production technologies. Addressing the gaps in space food research, the inclusion of post-harvest modules for processing and storing food is essential. Processing technologies also enables side stream and biowaste valorisation by reintroducing nutrients, producing packaging materials and utensils made from greenhouse side streams, or providing components for cultivated meat production. However, food handling on the Moon presents unique challenges due to reduced gravity, which affects heat and mass transfer, fluid behaviour, and physiochemical properties of food, necessitating the adaptation of processing methods and equipment to the space environment (10) (11) (12) (13) (14) (15). Moreover, the lunar environment, with its elevated radiation levels, can increase the pathogenicity of certain bacteria as well as improving microbial tolerance to intrinsic and extrinsic stressors which impacts food shelf-life stability and processing mechanisms (16) (17) (18). Hence, determining the requirements for storage facilities becomes crucial.

Previous closed-loop efforts, such as, Lunar Palace 1, the MELiSSA initiative and DLR's ModuLES approach, are mainly concentrated on simulations of closed loops with several breadboard test facilities. However, their integration with post-harvest management and the incorporation of humans in the loop have been limited. The project described here aims to bridge these gaps and establish a comprehensive framework for space food production, encompassing both pre-harvest and post-harvest technologies, as well as human involvement. By combining the post-harvest module with Controlled Environmental Agriculture (CEA) technologies from the EDEN-ISS greenhouse, the project seeks to create HABSIM, a research infrastructure for a multi-purpose closed-loop food production system essential for human survival on the Moon. The implementation of post-harvest management within HABSIM is crucial for achieving a truly sustainable and self-sufficient food production system in space. This will provide a technological layout of a future post-harvest management facility as a part of the bio-regenerative life support system and closed loop habitat, to minimize resupply missions from Earth and to establish an independent closed loop food production system. HABSIM, a research infrastructure for a multi-purpose closed-loop food production system, will be essential for human survival on the Moon. The implementation of post-harvest management is necessary for the feasibility and acceleration of research and innovation in space food development, as the HABSIM aims to integrate various research into a closed-loop system that will enable testing of technology synergies and humans-in-the-loop experiments. The project has garnered interest from research institutions and international space agencies such as National Aeronautics and Space Administration (NASA) and Canada Space Agency (CSA). The module is designed with circularity in mind, aiming to recycle and reuse water, heat, and gas, and utilize side stream and biowaste processing for nutrient reintroduction and natural product extractions. The goal is to achieve complete self-sufficiency in consumable materials, including packaging, tableware, utensils, and nutrient components, all derived from the closed-loop system.

The closed-loop food production technology developed through this project has applications beyond space, supporting independent food production and reducing external dependencies in challenging environments on Earth, aiding both rural and urban areas, and contributing to climate neutrality and humanitarian efforts. The project promotes collaboration among scientific, engineering, and industrial teams across Europe, strengthening scientific excellence and fostering leading-edge research of space food in and Europe.

References

1. Group, International Space Exploration Coordination. *Global Exploration Roadmap Lunar surface exploration scenario update.* Washington, DC : National Aeronautics and Space Administration, 2020.

2. *Developing the NASA food system for long-duration missions.* Maya Cooper, Grace Douglas, Michele Perchonok. s.l. : Journal of Food Science, 2011, Vol. 76.

3. *Space food experiences: Designing Passenger's eating experiences for future space trabvel scenarios.* Obrist, Marianna, Ty, Yunwen and Velasco. s.l. : Journal of Computer Science , 2019, Vol. 1.
4. *Limitations in predicting radiation-induced pharmaceutical instability during long-duration spaceflight.* Rebecca S. Blue, Jeffery C. Chancellor, Erik L. Antonsen, Tina M. Bayuse, Vernie R. Daniels & Virginia E. Wotring. 15, s.l. : Nature, 2019, Vol. 5.
5. Antonsen, Erik. *Risk of Adverse Health Outcomes and Decrements in Performance Due to In-flight Medical Conditions.* s.l. : NASA , 2017. 20170004604.
6. *Current processing and packing technology for space foods: a review.* Jiahui Jiang, Min Zhang, Bhesh Bhandari & Ping Cao. s.l. : Critical Reviews in Food Science and Nutrition, 2019. 60:21, 3573-3588.
7. *Sustaining Astronauts: Resource Limitations, Technology Needs, and Parallels between Spaceflight Food Systems and those on Earth.* Grace L. Douglas, Raymond M. Wheeler, Ralph F. Fritsche. s.l. : Sustainability, 2021, Vol. 13. 10.3390/su1316424.
8. *Biomass Production of the EDEN ISS Space Greenhouse in Antarctica During the 2018 Experiment Phase.* Paul Zabel*, Conrad Zeidler, Vincent Vrakking, Markus Dorn and Daniel Schubert. s.l. : Frontiers in Plant Science, 2020, Vol. 11.
9. *NASA food systems: Past, present, and future.* M Perchonok, C Bourland. 10, s.l. : Nutrition, 2002, Vol. 18.
10. Chao, David. *This International Space Station (ISS) Researcher's Guide. s.l. : NASA ISS Program Science Office, 2020.* . s.l. : NASA ISS Program Science Office, 2020.
11. *How foams unstable on Earth behave in microgravity?* H. Caps a, N. Vandewalle a, A. Saint-Jalmes b, L. Saulnier, P. Yazhgur, E. Rio, A. Salonen, D. Langevin. s.l. : Colloids and Surfaces A: Physicochemical and Engineering Aspects, 2014, Vol. 457.
12. *Does water foam exist in microgravity?* H. Caps, G. Delon, N. Vandewalle, R.M. Guillermic, O. Pitois, A.L. Biance, L. Saulnier, P. Yazhgur, E. Rio, A. Salonen, and D. Langevin,. 3, s.l. : Europhysics news, 2014, Vol. 43.
13. *Foam stability in microgravity.* N Vandewalle, H Caps, G Delon, A Saint-Jalmes, E Rio, L Saulnier, M Adler, A L Biance, O Pitois, S Cohen Addad. s.l. : Journal of Physics, Conference series , 2011, Vol. 327.
14. *Crystallization of hard-sphere colloids in microgravity.* Jixiang Zhu, Min Li, R. Rogers, W. Meyer, R. H. Ottewill, STS-73 Space Shuttle Crew, W. B. Russel & P. M. Chaikin. s.l. : Nature, 1997, Vol. 387.
15. *Soft matter approaches to food structuring.* Sman, R.G.M. van der. s.l. : Advances in Colloid and Interface Science, 2012, Vols. 176-177.
16. *Spaceflight and modeled microgravity effects on microbial growth and virulence.* Jason A. Rosenzweig, Ohunene Abogunde, Kayama Thomas, Abidat Lawal, Y-Uyen Nguyen, Ayodotun Sodipe & Olufisayo Jejelowo. 885–891, s.l. : Applied Microbiology and Biotechnology, 2010, Vol. 85.
17. *Modulatory effect of low-shear modeled microgravity on stress resistance, membrane lipid composition, virulence, and relevant gene expression in the food-borne pathogen Listeria monocytogenes.* Sunirmal Sheet a, Yesupatham Sathishkumar a b, Kuntal Ghosh c, Mi-Sook Choi a, Kwan Seob Shim d, Yang Soo Lee. s.l. : Enzyme and Microbial Technology, 2020, Vol. 133.
18. *Foods for a Mission to Mars: Investigations of Low-Dose Gamma Radiation Effects.* J. Gandolph, A. Shand, A. Stoklosa, A. Ma, I. Weiss, D. Alexander, M. Perchonok, L.J. Mauer1. s.l. : NASA technical reports, 2013.

Fighting poverty of West African Fishermen through Aquaponics Training Centre in Kokrobite, Ghana

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Keywords: aquaponics, education centre, regenerative agriculture

ABSTRACT

In this project, two complementary project goals are in the foreground:

1. Securing the long-term livelihood of the Kokrobite childrens and adult education Center KCC in Kokrobite, Ghana
2. The establishment of a regional West African Regenerative Agriculture Training Center that trains local fishermen in farmers in sustainable farming practices, including aquaculture, biochar, composting, etc.

Background

The school “Kokrobite Childrens Centre”, “KKC”, has grown to 1200 students since 2004. The two headmasters, Jane and Martial Zohoungbogbo, are concerned about the continued existence and would like to have the institution built on a secure financial and structural framework within the next 10 years so that their many years of social commitment can be continued after their retirement. Jane and Martial Zohoungbogbo have been actively building local capacity from the beginning and would like to turn day-to-day operations over to their current staff within the next five years. This will require ensuring that the operations are financially self-sustaining.

At the same time, a training center for sustainable fish farming on land is to be set up for fishermen in West Africa. Fishing on the coasts of West Africa has become a futureless activity due to deep-sea fishing; the catches are getting smaller and smaller, the coasts more polluted, the forests for the wood for smoking are cut down and the soil is impoverished.

Both project goals can be addressed with this project. By means of an integrated approach of closed material cycles, fish farming on land is made possible in a sustainable manner. The aquaponics approach (fish farming and plant breeding in a closed water cycle) offers the “poorest of the poor” the opportunity to build a livelihood without putting too much strain on nature. The West African fishermen should learn the aquaponics training in Kokrobite and be able to take the system home with them to replicate it. This creates a multiplication of sustainable fish farming in West Africa. Fishermen who have knowledge of fish handling and the fish market can gain a new perspective by switching to onshore fish farming and provide protein-rich food to their local communities.

The primary building and a first demonstration aquaponics system have been built with support from the entire Kokrobite community. Variations of Aquaponic systems have been tested. The construction work was carried out with PET bottles filled with sand, as bricks are too expensive.

After this series of demonstration systems, the integration of all work packages into a circular regenerative agriculture will start this year. Closing the loop locally brings decisive advantages: The nutrient cycle is closed, which replaces the purchase of feed or fertiliser, for example. It also reduces the ecological burden, as regenerative agriculture does not produce waste, but serves to build up valuable soil. This makes reforestation and crop cultivation possible.

Work packages

the work packages that will be trained at the West African Regenerative Agriculture Training Center are:

- Fish feed production using insect breeding from crop residues
- Fish farming on land with Aquaponics
- Production of vegetable charcoal with pyrolysis cookers
- Composting of fish waste with vegetable charcoal to build up humus
- Creation of latrines to recover organic material, which after fermentation and subsequent composting, also with vegetable charcoal, is used for reforestation.
- Sustainable fish drying with solar drying ovens and smokers to keep the typical taste with a reduced amount of wood needed
- House construction with reduced funds

The training center is to be built on the KCC premises in the next 5 years.

Project partners

The “International School of Zug and Lucerne”, “ISZL”, in Switzerland has been working with the KCC since 2013. During project weeks, volunteers work on the most necessary infrastructure projects. For example, the only library far and wide or drinking water treatment for 7000 people could be realized with the help of the ISZL in the KCC.
The aquaponics approach has been around for a long time. For the training of ISZL students, there is an aquaponics test facility on the campus in Hünenberg ZG as well as a model of an aquaponics facility that could be built in Ghana with the simplest of means. The ISZL students have already won international prizes with their efforts to implement aquaponics in Ghana. A test facility was built in Kokrobite in 2018 during an ISZL project week. However, it had to be removed again because the plot on which the facility was built had to be cleared. The structure of this system was also not suitable for multiplication. A completely new approach should enable simplified reproduction and integration into local material cycles.
In 2021, Ecological Engineer Raffael Känzig from Phoster GmbH was brought in to improve the Hünenberg aquaponics facility. Together with the students under the guidance of Humanities teacher Christopher Koch, the biological stability was raised to a significantly better level. Measures were almost exclusively of an eco-technological nature, i.e. the optimization of biological processes in aquaponics. Since 2023, Raffael Känzig is involved in the project in Kokrobite for the transfer of this knowledge and for the integration of aquaponics into the local material cycles. In June 2023, under his lead, a domestic aquaponic system has been set up in Kokrobite with low-tech materials such as sand-stuffed PET- bottles as brick replacement or Aircrete to save investment costs. This makes aquaponic systems available for the low-income community in West Africa.

Closing nutrient cycles with aquaponics

The term "aquaponics" combines fish farming on land and plant cultivation in soilless substrate. Fish farming benefits from the fact that the water from the planting is cleaned. The plants receive the fish water as fertilizer-containing water. The water is circulated with little effort. Aquaponics uses 90-95% less water than conventional farming, making it economical and less vulnerable to climate change.
Engineering an aquaponics facility that can be learned and copied with the simplest of means is the goal at the KCC Aquaponics Training Centre. Trainees should learn the principles of aquaponics and be able to copy the construction and recreate it at home.
Sustainable embedding in natural cycles will be important in aquaponic training at the KCC. In this way it can be ensured that the food is of high quality and that the ecological footprint can be kept small.
An example of this is the fish feed that Ghana still imports from unsustainable feed production in the US. The own feed production by breeding Black Soldier Flies from vegetable waste ensures independence from feed imports from the USA.
Another problem from fish farms, resulting sludge from fish excrement is composted with charred plant residues, possibly also from human faeces from dry toilets, mixed with biochar and used to clear and reforest firewood for cooking or smoking the fish.

The quality of the fish, but especially of the plants, is of central importance for acceptance in the "premium market" in West Africa. Imports of fresh produce from Europe by plane are currently used for high-quality vegetables. Vegetables in Ghana are not necessarily available in perfect condition; either the quality is often not right, or vast quantities of pesticides were used. With aquaponics, the latter is omitted due to the system. Business models are therefore being developed for the harvest from aquaponics in order to reliably supply the Ghanaian market with high-quality products. One possibility is a cooperative, which receives the goods from the hopefully numerous replica aquaponic systems, cools them and sells them to the customers. Conclusion: The products from aquaponics are accepted and in demand on local markets; smoked fish and good quality vegetables fetch good prices.

Project goal and impact

The construction of an aquaponic center pursues these goals:
Goal 1: Financial security for the KCC school
Goal 2: The training of aquaponic fish farmers from West Africa
Goal 3: Development of a competitive system for marketing harvests from aquaponic systems of all participants

Goal 1: Financial security for KCC
The KCC continues to fund children's education. With the upcoming retirement of Jane and Martial Zohoungbogbo in the next 10 years, there is a risk that the school will no longer be able to continue. With the Aquaponics Training Centre, the school has the opportunity to have another important financial basis by harvesting the training aquaponics facility.

Goal 2: Self-empowerment and training of West African fishermen
The KCC school trains the poorest of the poor from all over West Africa to practice sustainable fish farming on land. It offers them the chance to build up a livelihood with their work at home. This opportunity is also available for KCC school leavers. After school, the chances for a good job are rare. With the know-how from the school days in the KCC, the foundations have been laid for an option of being able to earn a living yourself.

Objective 3: Marketing of products from all aquaponic systems of the participants
A food center is to ensure the quality of the food from aquaponic systems. It buys the groceries from the small farms and is a trading partner in the "Premium Market" in Ghana for hotels and restaurants in the nearby capital Accra. This food center can be organized as a cooperative. The appropriate business model will be developed and implemented over the next 5 years.

Subsystems of integrated aquaponics in school KCC

- Aquaponic training unit
- Aquaponics domestic unit
- Charcoal kilt
- Insect fish food production
- Dry toilet for compost
- Raised beds for soil upgrading
- Reforestation

Urban Bioeconomy: Mapping Organic Resource Streams and the Bio-Symbioses in Cities through Geospatial and Material Flow Analysis

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Keywords: Urban Bioeconomy, Material Flow Analysis, Urban Food Systems, Biowaste Valorisation, Urban Farming, Green Infrastructure

ABSTRACT

Globally, the ecological footprints of cities, which are accountable for the majority of the world's resource and energy consumption, are increasing rapidly along with the exponential urbanisation rates. While cities and nature have traditionally been seen as diametrical opposites, the concept of Urban Bioeconomy strives to bridge this gap and to transform cities into bioeconomy hubs that assimilate to nature and manage their bioresources more efficiently. The concept focuses specifically on the biological side of cities and can therefore be seen as the bioeconomic subsection of the more widely known Urban Metabolism research. As resource accounting is often only conducted on national levels, the comprehensive bioresource flow data within urban and suburban environments will be highly valuable to create a local resource strategy for a sustainable future city.

To identify Urban Bio-Symbioses, i.e., the synergies between different bioeconomic sectors, this work maps the different bioresource streams within cities. It does so quantitatively by using Material/Substance Flow Analysis methods. Oxford and Singapore have been chosen as case studies as they represent two contrasting types of cities amongst developed countries in terms of population density, local conditions and land area. With this approach, the following research questions have been answered: 'How, where and when do biological resources currently enter, function within and exit urban environments? How do the current systems perform against a set of environmental criteria?' The focus was on the bioresources of the food system, green infrastructure and organic waste system.

Between Oxford and Singapore, the Material Flow Analysis in this work shows that Oxford imports most of its food and barely processes its organic waste within the city. It relies heavenly on its surroundings as it is embedded in a rural county. While Singapore similarly imports almost all of its food, an increasing amount of urban food production could be quantified in Singapore with its aim of 30% food self-sufficiency by 2030. Potential synergies between urban food systems and organic biowaste have been identified, e.g., the valorisation of wastewater and food waste to biofertilizers for urban agriculture. The Substance Flow Analysis of nitrogen and phosphorus, which are mostly responsible for eutrophication or greenhouse gas (GHG) emissions, shows that the majority of these nutrients can be found in wastewater and its valorised products like the digestate cakes.

This work is significant because it is, to our best knowledge, the first work that combines quantitative research methods on urban bioresource flows and their nutrient flows with the lens of identifying synergies between different bioeconomic components. In general, the concept of Urban Bioeconomy has been rarely academically explored although it gained traction among practitioners and policymakers

significantly. To help identify Urban Bio-Symbiosis opportunities, this research about the current state of cities laid the ground for future work on optimisations and improvements, including novel resource processing technologies, enhanced nature-based solutions and effective urban agriculture practices, towards a sustainable, circular Urban Bioeconomy.

Acknowledgements

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Analysis of the aquaponics system sustainability via system dynamics modelling – FEW nexus approach

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Keywords: aquaponics, food-energy-water nexus, sustainability, system dynamics modelling, agriculture

ABSTRACT

Aquaponic systems have been proposed as a sustainable solution for food production, since they recycle 98% of the effluent from aquaculture, almost completely reducing the load of wastewater released into the environment (Al-Hafedh *et al*., 2008). Therefore, it appears to be an environmentally viable system, especially considering nexus approaches as in the case of Food-Energy-Water.

Since the World Economic Forum (2011), the FEW Nexus approach have been seen as a conceptual and theoretical tool to understand the sustainability transition challenge. It presents the ability to take into account the interdisciplinary and multiscale objectives of the FEW dimensions. This fact is supported by the urgency to achieve resilience of food-energy-water components in light of climate change (Givens *et al*., 2018).

The quantification of interactive relationships between components of complex systems, as FEW nexus approach, allow analyses of potential trade-offs in scenarios that have multiple attributes. These analyses could be provided by System Dynamics Modelling (SDM) tool application (Forrester, 1961; 1968). The SDM is considered a robust methodology for analysing and understanding risk scenarios, prioritizing actions that consider uncertainty, optimize offsets, and reflect institutional capacity (Weiskop *et al*., 2020). Due to the complexity of the interrelationships between the components of the FEW nexus, the objective of the study is to analyse the sustainability of the aquaponics system through SDM simulations for socio-economic and environmental parameters.

Methodology

The study was developed applying data from the aquaponics company Symbiotec - Aquaculture and Integrated Production Systems Ltd. for food production, in this case Tilapia (*Oreochromis niloticus*) as fish and lettuce (*Lactuca sativa*) for vegetables. The pilot plant was designed for the region known as the “green belt,” composed of regions of the mega-metropolis of São Paulo. The green belt is located at the edge of the Atlantic Forest, evidencing the complexity of the analysis of the FEW (Food-Energy-Water) Nexus.

The establishment of benchmarking was carried out previously based on literature and technical protocols considering collected data from production systems and/or international protocols. The indicators were selected to organize a decision tree and its respective benchmarking values according to previous study (Dal Poz *et al*., 2022). The indicators in question are: a) Land Use Earnings [LUE] (R$/ha) - represents the average profitability of horticulture in rural properties (unit of analysis); b) Land Social Development Index [LSDI] (0 - 1) - developed in partnership with stakeholders consisting of five sub-indicators; c) Trophic State Index [TSI] (0 – 67): used in the measurement of the eutrophication process (CETESB, 2017; Lamparelli, 2004); d) Water Footprint [WF] ($m^3/ton_{product}$): considered a comprehensive indicator of the appropriation of water resources (Hoekstra *et al.*, 2011); e) Carbon Footprint [CF] (ton_{CO_2eq}/ha): measure of the total amount, in mass unit (scope 1 and 2) of greenhouse gas emissions (GHG Protocol, 2010). The SDM-Aqua

model (Figure 1) was developed in Anylogic® *University* 8.7.7. The systems represent the aquaponics system integrating fish and vegetable production on a scale of 200m².

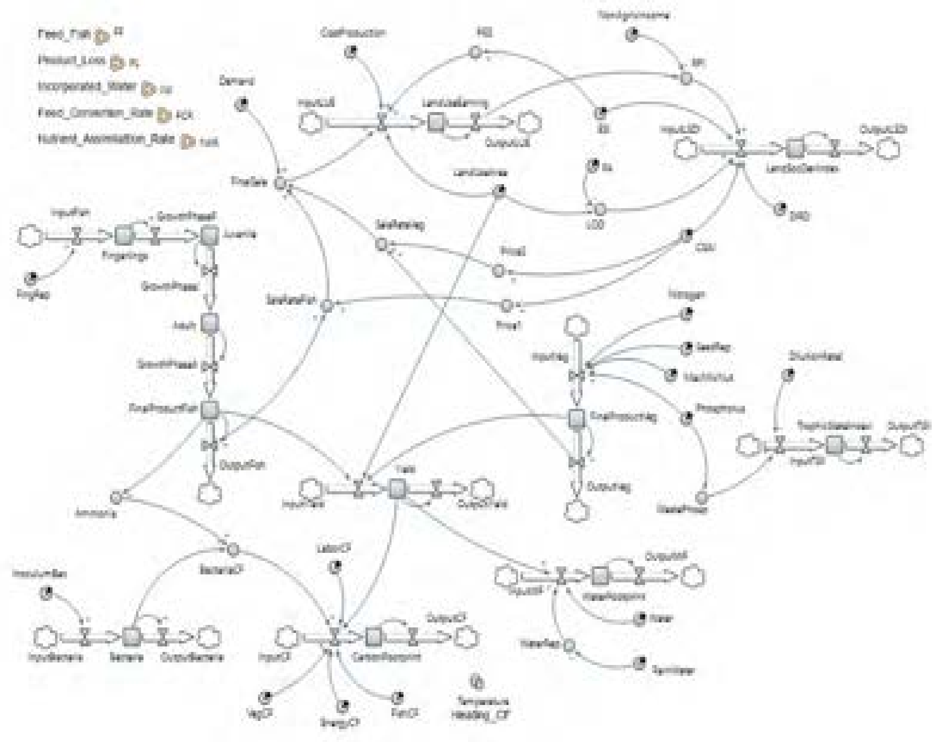


Figure 1: SDM-Aqua model that represents the process for the aquaponic system.

The equations used were developed by the SP in Natura Laboratory team or, obtained from a secondary source (literature). The databases of the Center for Meteorological and Climatic Research Applied to Agriculture (CEPAGRI/UNICAMP, 2021), Center for Advanced Studies in Economics Applied (CEPEA-Esalq/USP, 2021) and State Water Resources Fund (FEHIDRO, 2019) were used for climatology from Baixo Tietê Basin, products market (fish and vegetables) and water resources data, respectively.

The causality analysis between indicators and system components represents relevant strategies or policies implemented in the transition to more sustainable system. However, stands out that due to the complexity of the system studied, not all possible relationships were studied. For the indicators being studied, predictive scenarios were considered for a period of 10 years (120 months). Scenario 1 represents the real state of the production process, that is, processes that do not have the implementation of sustainable strategies. Scenarios 2-4 present the adoption of technologies or public policies identified as sustainable. In addition, Scenarios 5-6 were evaluated for the TSI and WF indicators, aiming to simulate environmental events, specifically a prolonged water crisis. The hypothetical simulation of a period of climate crisis considered a rainfall deficit of 30% and a dilution rate of the Baixo Tietê Basin (FEHIDRO, 2019) constant in its minimum mean.

The predictive scenarios were statistically evaluated by analysis of variance (ANOVA) for 95% significance, and the R programming language was used in the production of the graphs. The ANOVA statistical technique, used to perform comparisons between three or more groups in independent samples, met the statistical purposes since the indicators (stocks) are influenced by two or more components (parameters and/or dynamic variables), showing the needs to evaluate the degree of influence on causal relationships.

Results and Discussions

The Figure 2 presents the results for predictive scenarios for the indicators, their respective benchmarking (red line) and discussions.

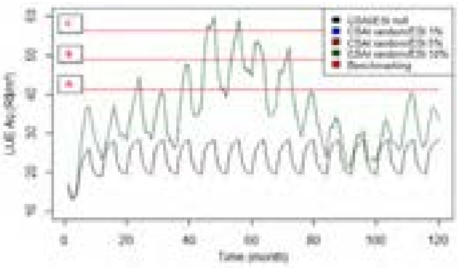
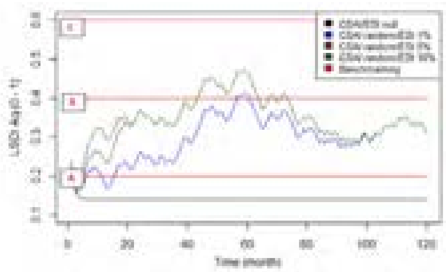
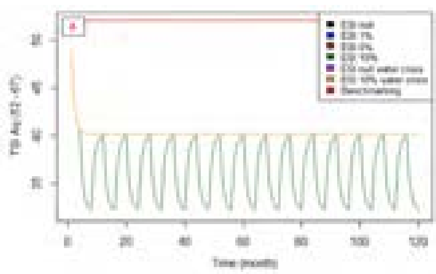
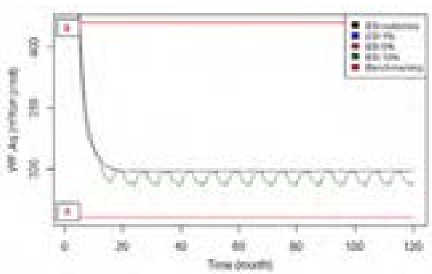
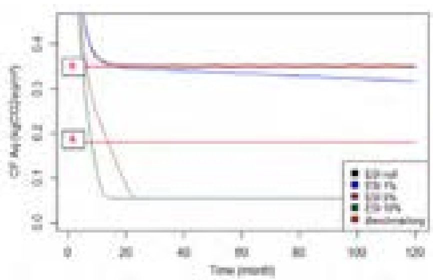
	The implementation of CSAI and ESI results in levels of greater sustainability for the system, directing the LUE to optimistic benchmarking when higher CSAI indices are tested. Furthermore, Payments for Environmental Services, hypothetically simulated according to Public Selection n°006 (2018), demonstrate a marginal effect on land use gains (LUE).
	The positive effect in the application of the tested policies is evident, a fact also highlighted for open systems (Francisco *et al*., 2023). A better level of sustainability is observed for scenarios 2-4, going from a step of lower sustainability, pessimistic level I, to higher levels, reaching a neutral level at certain times (benchmarking C).
	The analysis for the TSI, which represents the level of eutrophication in water sources, demonstrates that the aquaponics system is located in the benchmark with the highest level of sustainability, even for pessimistic scenarios. That is, it demonstrates sustainability even without the implementation of ESI strategies or periods of water crisis. However, additional studies are needed regarding the installation of some plants of these systems in the region.
	The WF indicator demonstrates that the aquaponic system has a sustainable profile, even in the case of non-implementation of rainwater reuse with ESI strategy on the studied scale. Similarly, to the TSI indicator, sustainability remains constant in the scenarios in which the water crisis was simulated.
	The emission of CO2eq, represented by the CF, is presented in the neutral band for the pessimistic simulation, that is, for the full use of the source of electric energy coming from the distribution system. Still, there is a small reduction in FC for scenario 2, directing the indicator to a degree slightly below neutrality (benchmarking B). As for scenarios 3-4, CF is drastically reduced, reaching the point of greater sustainability (benchmarking A).

Figure 2: Results from predictive scenarios from SDM-Aqua model.

Conclusion

The application of the system dynamics modelling tool in the analysis of the sustainability of the aquaponics system for the FEW Nexus proved to be robust and efficient for the indicators in question. Still, it is concluded that the use of the tool for decision-making and support for the development of public policies, their monitoring and evaluation, is seen as a potential ally for the governance of sustainability.

Regarding aquaponics, a system considered worldwide as an option for sustainable food production, analyses of predictive scenarios confirm the feasibility of its implementation in metropolitan regions. It emphasizes the need for public policy, in parallel with additional studies about socio-economic and environmental parameters, addressing the scheduling of production to meet the high demand for food in regions such as the mega-metropolis of the city of São Paulo.

Acknowledgements

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References

Al-Hafed, Y.S., Alam, A., Beltagi, M.S., 2008. Food production and water conservation in a recirculating aquaponic system in Saudi Arabia at different ratios of fish feed to plants. J. World Aquac. Soc., 39 (4), 510 - 520. https://doi.org/10.1111/j.1749-7345.2008.00181.x

CEPEA-Esalq/USP, Center for Advanced Studies in Economics Applied, 2021. https://www.cepea.esalq.usp.br/br (accessed 15 July 2021)

CAPAGRI/ UNICAMP, Center for Meteorological and Climatic Research Applied to Agriculture, 2021. https://www.cpa.unicamp.br/graficos (accessed 15 July 2021)

CETESB (Companhia Ambiental do Estado de São Paulo), 2017. Índices de Qualidade das Águas – Apêndice D. https://cetesb.sp.gov.br/aguas-interiores/wp-content/uploads/sites/12/2017/11/Ap%C3%AAndice-D-%C3%8Dndices-de-Qualidade-das-%C3%81guas.pdf (accessed 15 October 2021).

Dal Poz, M.E., Ignácio, P.S.A., Azevedo, A., Francisco, E.C., Piolli, A.L., Silva, G.G., Ribeiro, T.P., 2022. Food, Energy and Water Nexus: An Urban Living Laboratory development for sustainable systems transition. Sustainability, 14, 7163. https://doi.org/10.3390/su14127163

FEHIDRO, State Water Resources Fund. Plano de Bacia hidrográfica do Baixo Tietê, 2019. https://sigrh.sp.gov.br/public/uploads/documents//CBH-BT/12364/relatorioi-pbh-cbh-bt.pdf (accessed 15 July 2021)

Forrester J.W., 1961. Industrial dynamics. MIT Press, Cambridge, MA.

Forrester J.W., 1968. Principles of system dynamics. Productivity Press, Cambridge, MA.

Francisco, E.F., Piolli, A.L., Ignácio, P.S.A., Dal Poz, M.E.S. Food-Energy-Water (FEW) nexus: Sustainable food production governance through system dynamics modelling. Journal of Cleaner Production, 386, 135825, 2023. Doi: 10.1016/j.jclepro.2022.135825.

Givens, J.E., Padowski, J., Guzman, C.D., Malek, K., Witinok-Huber, R., Cosens, B., Briscoe, M., Boll, J., Adam, J., 2018. Incorporating Social System Dynamics in the Columbia River Basin: Food-Energy-Water Resilience and Sustainability Modeling in the Yakima River Basin. Frontiers in Environmental Science, v.6., 106, 1 – 19. https://doi: 10.3389/fenvs.2018.00104

GHG, Programa Brasileiro GHG Protocol, 2010. Available from: < https://www.ghgprotocolbrasil.com.br/> (accessed 19 February 2020).

Public Selection Notice n°006, 2018. Projeto Recuperação e Proteção dos Serviços Relacionados ao Clima e à Biodiversidade no Corredor Sudeste da Mata Atlântica do Brazil. Pagamentos por Serviços Ambientais – PSA. https://www.finatec.org.br/site/wp-content/uploads/2018/09/edital_PSA_006_2018.pdf (accessed 19 February 2020).

Weiskopf, S.R., Rubenstein, M.A., Crozier, L.G., Gaichas, S., Griffis, R., Halofsky, J.E., Hyde, K.J.W., Morelli, T.L., Morisette, J.T., Muñoz, R.C., Pershing, A.J., Peterson, D.L., Poudel, R., Staudinger, M.D., Sutton-Grier, A.E., Thompson, L., Vose, J., Weltzin, J.F., Whyte, K.P., 2020. Climate change effects on biodiversity, ecosystems, ecosystem services, and natural resource management in the United States. Science of the Total Environment, 733, 137782. https://doi.org/10.1016/j.scitotenv.2020.137782

World Economic Forum, 2011. Global Risks. Sixth Edition. https://www.weforum.org/reports/ global-risks-2011-sixth-edition (Accessed 29 November 2021).

Analysis of selected factors determining the possibility of introduction and effective operation of rainwater sharing systems for hydroponics in existing multi-family buildings

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Keywords: water demand, drinking water, urban agriculture, climate change, adopting to climate change effects, rainwater

ABSTRACT

The IPCC Special Report (IPCC, 2018) indicates that in 2017, ongoing man-made warming has already reached a value of about 1^0C above pre-industrial levels (probably between 0.8°C and 1.2°C), which is estimated with a high level of confidence. The developing climate changes and their effects, which can be observed with increasing frequency, and which become particularly burdensome in cities, make it necessary to take quick steps towards the transformation of cities. One of these effects may be shortages of tap water. Currently, water is becoming a scarce commodity in more and more places, as exemplified by cities in India (including Mumbai and Chennai) (Ghosh, 2021), and the "Zero Day" crisis from Cape Town is a confirmation of the possibility of water insecurity (Dugard, 2021).

In turn, ensuring the protection of water supply to cities, both in terms of quality and quantity, is an extremely important task carried out by water safety and security management. Water safety plans recommended by the World Health Organization (WHO) in 2004 through the document (WHO, 2004) are being developed and implemented, and the need to ensure water safety along the entire supply chain is reflected in legal regulations - i.e. in the Directive of the European Parliament and of the Council (EU) 2020/2184 on the quality of water intended for human consumption, adopted at the end of 2020. Such a situation forces the search for ways to effectively use the available tap water in accordance with the principles of the circular economy, but also the search for alternative water sources to traditional ones - precisely in order to secure water supplies for the city. Here, the idea of using rainwater is part of the direction of activities aimed at ensuring water security for cities in quantitative terms.

At the same time, the COVID 19 pandemic has shown that the world, and in particular cities with large concentrations of people, should be prepared for scenarios that until now were considered impossible. Thus, for instance, a sudden cut-off of large settlement units from food supplies should be treated now as a probable event.

The solution that meets these problems is the use of hydroponics partially fed with rainwater in urban multi-family buildings. The introduction of such hydroponic crops is one of the main objectives of the SmartFood research project based on the full proposal (Gontar et al., 2020). Nevertheless, this process must be preceded by multi-faceted research, also in terms of the possibility of introducing a rainwater sharing system into buildings for the needs of urban agriculture.

For these reasons, the SmartFood project carried out i.a. research work aimed at analyzing selected factors determining the possibility of introducing and effectively operating rainwater sharing systems for the needs of urban agriculture in common spaces of existing multi-family buildings in cities. The purpose of the analysis was to establish a list of basic questions that should be answered when selecting or prequalifying a building for the introduction of a water management system for its joint use for hydroponics. Such a list will allow a fast appraisal of the suitability of existing facilities to introduce semi-

automated farming into urban multi-family buildings in terms of rainwater supply, and will also allow an estimation of the number of buildings potentially suitable for this purpose.

The material for the study was the existing multi-family buildings located in cities, for which the introduction of rainwater sharing systems for the needs of hydroponics can be considered. In particular, the conditions in (or for) these buildings were analyzed in terms of the possibility of implementing this type of water systems. In addition, the material for the analysis was also data on rainfall in one of the Polish cities for the years 2016 - 2021 obtained from the Institute of Meteorology and Water Management - National Research Institute (IMGW - PIB), as well as literature data on the quality of rainwater flowing from the roof for different locations in Poland and in the world. The study also used study visits to existing buildings considered for the introduction of a rainwater sharing system, as well as collected photographic documentation on the occurrence of various conditions in multi-family buildings in terms of the introduction of rainwater sharing systems. The analysis was conducted on the basis of the literature and the knowledge and experience of the members of the research team in the field of environmental engineering (water and wastewater technology, water supply and sewage systems) and construction.
The scope of the analysis included such determinants as, i.a., material and area of the roof, availability of space in the building, permissible loads or the quality and quantity of rainwater. Another important issue turned out to be the availability and readability of architectural and construction documentation (including sanitary industry), as well as the possible affiliation of the object and area to the protection of the city (or provincial) preservation officer. The analyzed factors were divided into:
- direct factors (i.e. internal factors related to the building, its construction and location)
- indirect factors (i.e. external factors not directly related to the building).
This division is shown schematically in Figure 1.

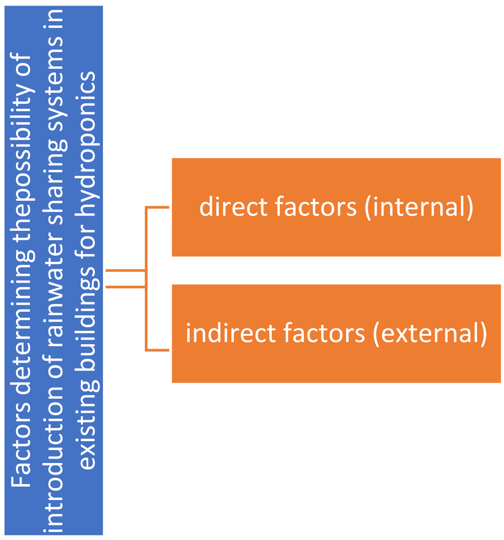

Fig.1. Division of factors determining the possibility of use of rainwater in existing buildings for hydroponics

The assumed final result of the research work in the form of a list of basic questions to which answers should be obtained each time, and then analyzed them in detail during the selection or qualification of the building for the implementation of the rainwater sharing system, was obtained in two stages. In table, the questions have been outlined with a brief explanation of why this is an important issue for building qualification, and the priority of the question. In addition, a detailed analysis of selected factors determining the implementation of this type of installation allows for a quick assessment of the building's conditions and possibilities of searching for ways to eliminate the existing restrictions.

The results of the work carried out will constitute a guide/guidelines for those willing to implement such a solution. It is also possible to transfer after modifications the obtained final effects when introducing rainwater utilization system to existing buildings used for other purposes than hydroponics.

Acknowledgements

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References:

IPCC, 2018: Global Warming of 1.5°C.An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, 616 pp. https://doi.org/ 10.1017/9781009157940.

Team work under guidance Gontar, Ł. (PI), SmartFood – engaging cities in food biodiversity – full proposal, IdeaLab call, 2020.

Ghosh, P. (2021). Water Stress and Water Crisis in Large Cities of India. In: Mishra, R.K., Singh, R.B., Dubey, A. (eds) Sustainable Climate Action and Water Management. Advances in Geographical and Environmental Sciences. Springer, Singapore. https://doi.org/10.1007/978-981-15-8237-0_11

Dugard, J. Water Rights in a Time of Fragility: An Exploration of Contestation and Discourse around Cape Town’s “Day Zero” Water Crisis. *Water* 2021, *13*, 3247. https://doi.org/10.3390/w13223247

World Health Organization (WHO), Guidelines for Drinking-Water Quality. 3rd Edition, Geneva, 2004.

Dyrektywa Parlamentu Europejskiego i Rady (UE) 2020/2184 w sprawie jakości wody przeznaczonej do spożycia przez ludzi, Dz.U.UE L z dnia 23 grudnia 2020 r.

Close cycle approach in a food farm in Reggio Emilia, Italy

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Keywords: circular economy, sustainability, resource recovery and reuse, treatment wetlands, spirulina, food supplement

ABSTRACT

Circular economy can be defined as a function of a metric, departing from a well-defined material flow and value system. Recently it has been proposed as a metric that is derived from maximizing the value to society of materials used in the production of commodities that provide services to consumers (García-Barragán,2019; Stefanakis,2021). Treatment wetland (TW) are a compatible component of an on-farm, total waste management. The land intensiveness is not a serious limitation in most instances. Farmers typically have the equipment and skills to build their own TW and operate them successfully (Kadlec,2009). The case studies provide the evidence of how a circular economy and close cycle approach can be applied in practice while highlighting co-benefits of resource recovery and reuse. The 5 hectares Villacanali food farm situated in Reggio Emilia - Italy, produces since 2020 agricultural products and spirulina microalgae (cyanobacteria, Selitto V.M., 2021) for human food supplement in 500 special greenhouses called photobioreactor, with capacity of 500 litres each, that takes solar radiation and directs it into the photobioreactors via optical fiber.

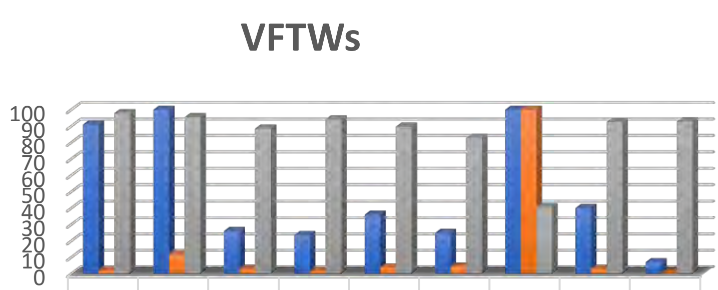
Figure 1: photobioreactor for growing of spirulina microalgae; spirulina microalgae preparation and drying

In order to treat the domestic and industrial farm's wastewater a sub-surface vertical flow treatment wetland (VFTWs) has been designed. In the industrial line, after the water and nutrient are recycled inside the photobioreactor, the exhausted algal culture medium called "extinct medium" with algae residues and softened water is discharged and accumulated in two tank of 40 m^3 before immitted in the VFTWs. The domestic line treats wastewater from 3 farmers houses and employees' toilettes.
Clogging in VFTWs is an important process influencing water purification processes. The main contributing factors are the growth of microorganisms within the filter media, the accumulation of suspended solids on top of the wetland, as well as within the filter media. Both processes lead to a decrease of the available pore space, hence changing the soil's hydraulic properties (Pucher,2019). To prevent clogging all the raw wastewater go into two septic tanks of 9 m^3 (industrial) and 5 m^3 (domestic) functioning for sedimentation and removal of particulate matter as primary treatment before reaching the VFTWs through a loading tank with submersible electric pump that pumps the sewage four times a day.
In VFTWs, primary treated wastewater is intermittently loaded on the surface of the filter and percolates vertically through it. During two loadings, air re-enters the pores and aerates the filter so that aerobic degradation processes mainly occur. The treatment efficiency and acceptable organic loading rate depend heavily on the granularity of the filter media used (K. Cross, et al.2021). The VFTWs of Villacanali farm has

been designed with a main layer of 60 cm of washed sand (1-4 mm), a 10 cm intermediate gravel layer (8-16 mm) and a 20 cm drainage layer (16-32mm). Emergent wetland vegetation has been used: *Phragmites australis* (4 plants/m^2).

There are many ways to size and design a treatment wetland system (TW). Over recent decades, TW design approaches have evolved, but for VF wetlands only rule-of-thumb and loading charts are applicable (G. Dotro et al.,2017). The VFTWs of Villacanali farm has been design considering organic and hydraulic load of the inflow and a surface area of 4 m^2/p.e. The industrial wastewater is assimilated to domestic according to the chemical-physical analysis (pH 7,7; BOD5 91 mg/l ; COD 262 mg/l; SST 26 mg/l ; N- NH4 23,5 mg/l; N-NO3 36 mg/l; total P 24,8 mg/l; chlorides 740 mg/l, fats and oils 50 mg/l, surfactants 4,1 mg/l). The influent rate flow is of 6,6 m^3/g corresponding to 33 p.e. The superficial hydraulic loading rate (HLRs) is 0,06 m^3/m^2*d so lower than 0,1 m^3/m^2*d as suggested by specific literature (Langergraber G., et al., 2017). The organic loading rate is 2,38 g COD/m^2*d. The system treatment efficiency is: BOD5 98% ; COD 95%; SST 88% ; N- NH4 94%; N-NO3 90%; total P 83%; chlorides 41%, fats and oils 93%, surfactants 93%.

The treated water outflow from the VFTWs is accumulated in a pond of 100 m^3 and reuse inside the farm for gardening, landscaping and for fruit crops irrigation. The final overflow is in a little stream called Rio Acqua Chiara.



	BOD5	COD	SST	N-NH4	N-NO3	Total P	Chlorides	Fats and oil	Surfactants
IN	91	262	26	23,5	36	24,8	740	40	7
OUT	2	12	3	1,4	3,7	4,27	440	3	0,5
EFFICIENCY %	98	95	88	94	90	83	41	93	93

IN OUT EFFICIENCY %

Table 1: the vertical flow treatment wetland removal efficiency

Figure 3: the vertical flow treatment wetlands (VFTWs) during construction

Today a new vision of the water management and sanitation approach is receiving increasing attention; this new paradigm considersresource recovery as a factor of primary importance and clearly highlights the consequences of the “end-of-pipe” approaches (centralised and undifferentiated water supply and wastewater treatment, great role of extensive and extremely costly infrastructures such as sewers and pipelines, scarce consideration of the environmental carrying capacity of specific urbanised territories, etc.) (Stefanakis et al., 2014). The innovative approach of the circular design of Villacanali treatment system will minimize the total consumption of fresh water of the farm and also reduce the pollution load on the public sewerage system using a decentralized wastewater treatment system (DEWATS).

References:

Cross K., Tondera K., Rizzo A., Andrews L., Pucher B., IsteničD., Karres N.,. McDonald R,2021. Nature-based solution for wastewater treatment , a series of fact sheets and case studies. IWA Publishing, Alliance House, 12 Caxton Street, London SW1H 0QS, UK http://iwaponline.com/ebooks/book-pdf/915777/wio9781789062267.pdfby guest

Dotro G., Langergraber G., Molle P., Nivala J., Puigagut J., Stein O., Von Sperling M., IWA Task Group on Mainstreaming the Use of Treatment Wetlands, 2017. Biological Wastewater Treatment Series vol.7 Treatment Wetlands. IWA Publishing Alliance House, 12 Caxton Street, London SW1H 0QS, UK Downloaded from http://iwaponline.com/ebooks/book-pdf/894754/wio9781780408774.pdf by guest

García-Barragán J.F. , Eyckmans J., Rousseau S. , 2019. Defining and Measuring the Circular Economy: a mathematical approach. Ecological Economics, vol. 157, March 2019, pp. 369-372, Elsevier Science, Amsterdam, Neaderlands

Kadlec, R.H., Wallace, S., 2009. Treatment Wetlands. CRC Press Taylor & FrancisGroup, Boca Raton, London, New York.

Langergraber G., Prandtstetten C., Pressl A., Haberl R., Rohrhofer R. , 2007. Removal efficiency of subsurface vertical flow constructed wetlands for different organic loads. Water Science and Technology 56(3):75-84.

Pucher B., Langergraber G. The State of the Art of Clogging in Vertical Flow Wetlands. *Water* 2019, *11*(11), 2400 https://doi.org/10.3390/w11112400

Sellitto V. M., 2021. Microalghe (e cianobatteri). I microrganismi fotosintetici in agricoltura.Edagricole, Bologna, Italy

Stefanakis, A.I., CS. Akratos, VA.Tsihrintzis, 2014. Vertical flow constructed wetlands: eco-engineering systems for wastewater and sludge treatment. Elsevier Science, Amsterdam, Neaderlands

Stefanakis, A.I., Nikolaou, I., 2021. Circular economy and sustainability, Volume 1. Elsevier Publishing

OPTIMIZATION OF WHEAT NUTRITION FOR REGENERATIVE AGRICULTURE

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Keywords: fertilizer rates, nitrogen, phosphorus, potassium, silicon, wheat yield

ABSTRACT
The study aimed to evaluate the effect of interaction between different rates of fertilizers: nitrogen, phosphorus, potassium, and silicon on the vegetation of Wheat (*Triticum aestivum* L). The plant height from the beginning of the experiment and yield at harvest were studied. The trials are conducted on two soils with contrasting soil properties. The study is in the field of regenerative agriculture. Optimization of Wheat nutrition was the main task, especially with silicon nutrition. The neglected until recently element, silicon proves to be extremely necessary and useful for the development of crops and protects them from disease and climate change, and suppresses toxic elements. The results are based on a multifactorial field experiment, which is 1/2 replication of a 2^4 factor scheme with added control variant that allows the assessment of actions and interactions of four factors, varying on three levels. According to the results, the agronomic characteristics were affected significantly by fertilization on the selected soils - Pelic Vertisol and Eutric Livisol. Results with silicon fertilization are discussed in detail.

Introduction
Ecological engineering was introduced by Howard Odum and others as utilizing natural energy sources as the predominant input to manipulate and control environmental systems (Wikipedia). The present study claims to belong to the field of Ecological Engineering.
Currently, several new ideas and directions have emerged in the field of environmental engineering. Some of them will be mentioned here. The European Parliament's report on "Precision agriculture and the future of farming in Europe" defines precision agriculture as: "a modern farming management concept using digital techniques to monitor and optimize agricultural production processes". The key point here is optimization. This leads to optimized fertilizer usage, saving coast, and reducing the environmental impact (EPRS, 2016). In the IAASTD report, agroecology is mentioned relatively few times, although many elements of how it is seen today were already in the report (IAASTD, 2009). Agroecology was presented as the science of applying ecological concepts and principles to the design and management of sustainable agroecosystems, including the study of the ecological processes in farming systems and processes. Regenerative agriculture means a perspective steeped in the use of plant, soil, ecological, and system sciences to support the production of food, feed, and fiber sustainably (Giller et al., 2021).
An effective tool for analyzing problems in regenerative agriculture is Mathematical Agronomy a theory of mathematical models of agronomic objects, processes, and phenomena (Sadovski, 2020).
Wheat (*Triticum aestivum* L.) is one of the most important cereal crops in the world on account of its wide adaptability to different agroclimatic conditions and different soils. The total cultivated area of wheat in the world is 240.00 million hectares with an annual production of 765 million tonnes (FAOSTAT, 2020). In Bulgaria, wheat is the first most important food crop; with a cultivated area of 1 198 682 hectares in 2019 which produced 6.2 million tonnes, with average productivity of 5140 kg.ha^{-1} (Agrarian Report, Bg, 2020). Bulgaria has many competitive advantages in the development of the agricultural sector (favorable climatic conditions, inexpensive labor, and raw materials, convenient location to global sales markets). Intensive agricultural activity is accompanied by a decrease in soil fertility, environmental pollution, and a decrease in production quality (Nenov, M., I. Dimitrov, V. Lozanova, I. Gerassimova, N. Traikov, 2020). Therefore, it is necessary to implement new, environmentally safe, and, highly effective methods of managing agricultural production (Ur, Zl., E. Vasileva, 2014).

The reduction of soil fertility and the agricultural production quality is associated to a significant extent, with the unbalanced nutrition of grown crops (Davies et al., 2020). The management of modern agriculture requires the fertilization of the soil to take into account the need to preserve the ecological equilibrium created during the soil formation process. This will be achieved by improving key elements in agrotechnology, such as fertilization and crop rotations.

The use of the previously neglected element of silicon (Si) can contribute to increasing the quantity and quality of yields, as well as to the sustainability of crops. Silicon is known to play a role in strengthening the cell wall in plants and can therefore help to give plants increased resistance to pests and diseases, impaired tolerance to drought and heavy metals, and enhance both crop quality and yields (Savant et al., 1999; Atanasova et al., 2022; Hou et al., 2023). Every year, 20 to 700 kg of Si/ha are irreversibly removed from the soil (Bocharnikova & Matichenkov, 2012). Silicon content in some regions might be limited to sustainable crop production. The need for proper Si management to increase yield and sustain crop productivity appears to be necessary in temperate as well as tropical countries. In addition, Si diminution in the soil can occur in intensive cultivation practices and continuous monoculture of high-yielding cultivars. (Korndörfer &. Lepsch, 2001).

This study aims to acquire new knowledge through experimental and theoretical activity to develop the scientific basis of appropriate recommendations for optimal fertilization of wheat and to clarify the role and importance of the main macroelements including silicon for plant nutrition.

Materials and Methods

In the experimental fields of ISSAPP "N. Pushkarov" in Bozhurishte, Sofia district and in Tsalapitsa, Plovdiv district, field experiments with the application of mineral fertilizers - N (ammonium nitrate), P (superphosphate), K (potassium sulfate), and Si (diatomic soil which represents 89-95% silica in amorphous form) are conducted. The experiments include 9 variants of fertilization with the size of the experimental parcels - 25 m^2. The design of treatments is presented in Table 1.

The test culture was Wheat (*Triticum aestivum* L) - medium-early Bulgarian sort "Sadovo 1", which used to be a national standard. The trials are conducted on two soils with contrasting soil properties. The soil in Bozhurishte is Leached smolnitza according to Bulgarian classification (Koinov, 1987) and it is defined as Pelic Vertisol - according to (FAO, 2015). The soil in Tsalapitsa is Alluvial-meadow and it is defined as Eutric Livisol. Soil properties and agrochemical characteristics getting before starting the experiment are presented in Tables 2 - 5.

The following methods of analysis are used: determination of Hummus - by oxidation during heating along with the Turin (Kononova, 1963); pH- potentiometrically in H_2O and KCl (Arinushkina, 1962); total N – by Kjeldahl (Buffler & Mühleis, 2018), mineral N - Bremner and Kiney method (Bremner, 1965a; Bremner, 1965b); mobile forms of phosphorus and potassium (P_2O_5 and K_2O) by the acetate method of Ivanov (Ivanov, 1984). Silicon analysis of soluble and exchangeable forms by acetic acid and calcium chloride (Snyder, 2001; Heckman & Wolf, 2009).

The plant height on the 195th, 222nd, and 248th day from the beginning of the experiment and the yield of fresh and dried biomass from the aboveground part of the crop at harvest were studied.

For the statistical processing of the data, the One-way-ANOVA method was used from the package Statgraphics 18 program (StatPoint, 2017). To identify the differences between the variants studied, the least significant differences (LSD) were used at $p \leq 0.05$ (95%). Optimization was performed by the free software package GNU Octave (2021).

Results and Discussion

Experimental design, which is 1/2 replication of a 2^4 factor scheme with added control variant was used in the planning of multifactorial experiments that allow the assessment of actions and interactions of more than three factors, varying on three levels (Davies, 1954, page 455).

Results from soil tests for soluble and exchangeable silicon and corresponding yields from two experimental fields are presented in Table 6.

Results of multiple regression analysis of yields from Bozhurishte and Tsalapitsa are given in Tables 7 and 8.

The following regression equations are obtained

For Bozhurishte:

$$Y = 249.8+6.113*N+19.760*P+23.850*K-90.190*Si+0.935*NP-2.228*PK+9.376*KSi$$

The regression equation is with $R^2 = 0.8312$, but almost all of the regression coefficients are not significant. The soil equivalent for silicon from Pelic Vertisol calculated is $X_0 = 0.4417$ (Sadovski, 2021).
With its help, the equation was received in the form

$$Y = a(X_0 + F)^b \exp[c(X_0 + F)].$$

$$Y = 871.312*(0.4417+F)^{1.2430} * e^{(-0.5287*(0.4417+F))}$$

The optimization gives the following result:
F = 1.909 kg/da
Y = 727.49 kg/da
For Tsalapitsa:

$$Y = 457.80+59.91*N+54.90*P-50.70*K-209.70*Si-4.768*NP+3.179*PK+4.796*KSi$$

The regression equation is obtained with $R^2 = 0.5185$, and is not suitable for optimization purposes.
The soil equivalent for silicon from Eutric Livisol calculated is $X_0 = 0.4033$.
The equation was received

$$Y = 836.31*(0.4033+F)^{0.5432} * e^{(-0.2705*(0.4033+F))}$$

Results from optimization are
F = 1.605 kg/da
Y = 709.47 kg/da

Conclusions

As a result of the experiment with silicon fertilization on Pelic Vertisol and Eutric Livisol the following conclusions are drawn. Comparison of the quantity of soil silicon determined at sowing and harvest shows depletion of this nutrient. The presented examples from experiments confirm the practical benefit of using the soil equivalent in processing the results of field experiments. At Pelic Vertisol optimal quantity of silicon F = 1.909 kg/da gives maximum yield of Y = 727.49 kg/da. Maximum yield of Y = 709.47 kg/da at Eutric Luvisol is obtained with optimal quantity of silicon F = 1.605 kg/da. It is recommended for European scientists to conduct extensive studies on the influence of silicon on different crops.

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References:

Agrarian Report. (2020). Annual report on the state and development of Agriculture. Ministry of Agriculture, Food and the Forestry, Sofia. (Bg).
Arinushkina, E. V. (1962). Guide for chemical analysis of soils. Moscow State University Press, Moscow, 490 (Rus).
Atanassova, I., Z. Petkova, A. Sadovski. (2022). Silicium – the element of plant and human health. Ecological Engineering and Environment Protection, No 3-4, p. 5-15.
Bocharnikova, E. A., Matichenkov. (2012). Influence of plant associations on the silicon cycle in the soil-plant system. *Applied Ecology and Environmental Research, 10 (4),* 547-560.
Bremner, J. M. (1965a). Organic nitrogen in soils. *Agron*. *10*, 93-149.
Bremner, J. M. (1965b). Inorganic forms of nitrogen. In: Black C. A. et al. (eds.). *Methods of soil analysis*, *part 2, Agronomy Monograph No. 9,* ASA and SSSA, Madison, 1179-1237.
Buffler, M., A. Mühleis. (2018). Kjeldahl Proficiency Guide. BÜCHI Labortechnik AG, Switzerland.
Davies O.L. (1954). The design and analysis of industrial experiments. Oliver and Boyd, London, pp. 654.
Davies, B., Coulter, J. A. & Pagliari, P. H. (2020). Timing and rate of nitrogen fertilization influence maize yield and nitrogen use efficiency. *PLoS ONE , 15(5),* e0233674. https://doi.org/10.1371/journal.pone.0233674
EPRS. (2016). Precision agriculture and the future of farming in Europe. Scientific Foresight Study. PE 581.892, ISBN 978-92-846-0475-3. DOI: 10.2861/020809.
FAO. (2015). World Reference Base for Soil Resources, 2014. FAO, Rome. 203. http://www.fao.org/3/i3794en/I3794en.pdf
FAOSTAT Food and Agriculture Organization of the United Nations. Available online: http://www.fao.org/faostat/en/#home

Gaj, R. (2008). Sustainable management of phosphorus in soil and plant in condition of intensive plant production. In: *Adaptive soil management - From theory to practices*. *Fertilizers and fertilization*. Springer, Berlin, Germany. *33*, 143.

Giller, K. E., Hijbeek, R., Andersson, J. A., & Sumberg, J. (2021). Regenerative Agriculture: An agronomic perspective. *Outlook on Agriculture*, *50*(1), 13–25.

Heckman J.R., A. Wolf. (2009). Recommended Soil Tests for Silicon. Cooperative Bulletin. **Northeastern Regional Publication No. 493,** 3rd Edition.

Hou L, Ji S, Zhang Y, Wu X, Zhang L and Liu P (2023) The mechanism of silicon on alleviating cadmium toxicity in plants: A review. Front. Plant Sci. 14:1141138. doi: 10.3389/fpls.2023.1141138

IAASTD. (2009). McIntyre, B.D. Synthesis report with executive summary of a synthesis of the global and sub-global IAASTD reports. Island Press, Washington, DC. ISBN 978-1-59726-550-8

Ivanov, P. (1984). New acetate-lactate method for determination of available forms of P and K in soil. *Soil Science and Agrochemistry*, *19 (4),* 88-98 (Bg).

Kononova, M.M. (1963). Soil organic matter. Its nature, properties and methods of study. M., AN SSSR, 314 p.

Korndörfer G.H., I. Lepsch. (2001). Effect of silicon on plant growth and crop yield. In: Datnoff L.E., G.H. Snyder, G.H. Korndörfer r (Eds.). Silicon in Agriculture. Elsevier, p. 133-147.

Koynov, V. (1987). Correlation between the soils of Bulgaria and the soils distinguished by the major soil classification systems in the world. *Soil Science, Agro-Chemistry and Plant Protection, 22(5)*, 5-13 (Bg).

Nenov, M., I. Dimitrov, V. Lozanova, I. Gerassimova, N. Traikov (2020). Optimization of agrotechnical units in grain production technologies in Sofia region. Field studies agrochemistry and ecology, 54, 3. page 28 -40. (Bg)

Octave Project. (2021). GNU Octave. https://www.octave.org/

Sadovski A. (2020). An Introduction to Mathematical Agronomy: Theoretical and Experimental Bases. LAP Lambert Academic Publishing, 2020. ISBN 978-620-2-51889-5, 284 pp.

Sadovski, A. N. (2021). Determination and use of the soil equivalent in fertilizer experiments. Rastenievadni nauki, 58(1) 62-67.

Savant, N. K, Korndorfer, G. H., Datnoff, L. E. and Snyder, G. H. (1999). Silicon nutrition and sugarcane production: a review. J. Plant Nutr. 22 (12):1853-1903.

Snyder G.H. (2001). Methods for silicon analysis in plants, soils, and fertilizers. In: Datnoff L.E., G.H. Snyder, G.H. Kornd6rfer (Eds.). Silicon in Agriculture. Elsevier, p. 185-196.

StatPoint. (2017). STATGRAPHICS Centurion 18. StatPoint Technologies Inc. https://www.statgraphics.com.

Ur, Zl., E. Vasileva. (2014). Effectiveness of wheat fertilization (Tr. aestivum) when changing certain elements in agrotechnical: VII. Efficiency of nitrogen use from fertilizers. Bulgarian Journal for Crop Science, 51(1): 109-113.

Wikipedia. Ecological engineering. Access on 28.04.2023. https://en.wikipedia.org/w/index.php?title=Ecological_engineering&oldid=1141488473

Session B5: Bioenergy, Renewable energy systems and energy efficiency

Carbon neutrality of energy produced from woody biomass

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Keywords: bioenergy, forest biomass, carbon neutrality, climate change

ABSTRACT

A long-standing debate is whether the use of biomass from forests is carbon-dioxide neutral or whether the use of biomass compromises the efforts to reduce the emissions of climate change. The question is of prime relevance because Europe is seeking independence, or at least a reduction of the dependence on fossil fuels, which are provided by the commonly known suppliers of raw oil and the former supplier of natural gas. A plethora of energy sources is proposed, ranging from tidal energy, energy from windmills, photovoltaics, bioenergy, and the production and use of hydrogen. In some (few) countries of the world bioenergy from woody biomass can supply energy.

A challenge of renewable energy sources is the limited control of energy supply. The intermittently energy sources from wind and photovoltaics are a major obstacles for energy suppliers. Whereas gas turbines can be turned on and off in order to balance the energy supply, other renewable energy sources are less reliable, or less predictable. Bioenergy from woody biomass is available on demand.

In our presentation we present a case study for Austria and interpret the results with respect to the relevance of biological processes and with respect to ecological concepts. Key issues are the wide definitions of sustainability and carbon neutrality. The theoretical concepts are therefore open for criticism. Both concepts affect the debate on carbon neutrality because they are open for interpretation.

In our paper we make a case that the use of bioenergy is carbon neutral in Central and Northern Europe. The reason for this opinion is based on facts that are inherent in the known dynamics of forests over time: forest biomass has increased year after year, external factors such as nitrogen enrichment and climate change, and internal factors such as improved forest management have increased the standing stock of biomass year after year. It is relevant to quantify and interpret this effect in the context of forest management. In addition, we interpret strengths and weaknesses of different concepts of carbon neutrality.

Will the energy supply from forest biomass be a significant contribution to the energy supply of Europe or not? – We address this question with hindsight to regional differences. The authors conclude that wood biomass in the current strategy of its use is sustainable. Changing the energy supply within even small margins may be problematic from the viewpoint of sustainability.

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References:

Mather-Gratton, Z. J.; Larsen, S. & Bentsen, N. S. Understanding the sustainability debate on forest biomass for energy in Europe: A discourse analysis. PLOS ONE, Public Library of Science, 2021, 16, 1-30

Cowie, A. L.; Berndes, G.; Bentsen, N. S.; Brandão, M.; Cherubini, F.; Egnell, G.; George, B.; Gustavsson, L.; Hanewinkel, M.; Harris, Z. M.; Johnsson, F.; Junginger, M.; Kline, K. L.; Koponen, K.; Koppejan, J.; Kraxner, F.; Lamers, P.; Majer, S.; Marland, E.; Nabuurs, G.-J.; Pelkmans, L.; Sathre, R.; Schaub, M.; Smith Jr., C. T.; Soimakallio, S.; Van Der Hilst, F.; Woods, J. & Ximenes, F. A. Applying a science-based systems perspective to dispel misconceptions about climate effects of forest bioenergy. GCB Bioenergy, 2021, 13, 1210-1231

An Innovative Approach Towards Energy Conservation Using Single RGB Camera Technology for Obtaining Occupant Location in Buildings

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Keywords: Occupant-centric control, Occupant location, Computer vision, Depth estimation, Energy saving, Indoor positioning

ABSTRACT

1. Introduction: Reducing energy usage in buildings is extremely important for promoting different low-carbon communities and advancing eco-friendly architectural practices. An approximate 40% of the total energy consumed globally can be traced back to buildings. Predominantly, this consumption arises from Heating, Ventilation, and Air Conditioning (HVAC) systems and lighting apparatus designed to ensure the comfort of occupants (Yau & Hasbi, 2013). Therefore, it's crucial to better understand how people behave in buildings to effectively decrease energy usage. In this context, occupant location information assumes a critical role, influencing energy conservation strategies from the design phase through to operation. During the design stage, comprehending the occupant's spatial pattern profoundly impacts decisions on the positioning of heating or cooling ducts and the magnitude of the HVAC apparatus. Erroneous identification of these patterns at this stage can lead to the installation of surplus heating and cooling devices, consequently triggering energy wastage due to over-equipped devices. Furthermore, during the operational phase, recognizing the occupant's spatial patterns can prompt a significant reduction in energy usage when operating HVAC and lighting systems, achieved by suspending the operation of such systems in unoccupied spaces.

A variety of techniques for automatically obtaining occupant location information are currently in place. Passive Infrared (PIR) sensors, though basic, have limitations as they cannot reliably detect stationary occupants, nor can they accurately count multiple individuals moving together (Andrews et al., 2020). CO2 sensors, which are widely used and cost-effective for occupant detection, require careful usage due to potential reliability issues caused by factors such as ventilation, door positions, and external CO2 levels. (Chen et al., 2018). Bluetooth positioning technology provides an affordable and precise solution, but its efficacy is questionable due to many devices and mobile phones used by occupants not enabling Bluetooth transmission (Tekler et al., 2020). In response to these challenges, camera-based techniques for detecting occupant in indoor environments has emerged. Cameras have not only become cheaper, but improvements in computer vision have also enabled the precise detection of multiple individuals. Furthermore, using camera-based technology can result in more advanced energy-saving systems, because it can provide precise information about where individuals are located at different times, in addition to their spatial data. For example, the introduction of Personalized Ventilation (PV) systems - adjustable units placed near each workstation to meet individual needs - has shown the potential of this technology (Wang et al., 2021). These PV systems have proven to save up to 51% of energy by adjusting the microclimate surrounding each occupant (Schiavon et al., 2010). Moreover, the precise detection of occupants has proved to decrease the energy consumption in lighting control. By turning off lights in unoccupied areas and only illuminating specific zones occupied by individuals, unnecessary energy consumption of individual lighting fixtures can be minimized.

Numerous studies have utilized cameras for automatically obtaining occupant location information and introduced the energy-saving systems based on it. For example, Chun et al. introduced a real-time smart lighting control system based on occupant location estimation utilizing inverse-perspective mapping of depth map images and location data from multiple depth cameras (Chun et al., 2015). Liu et al. suggested a tracking cooling fan using marker and camera-based occupant location detection for thermal comfort and energy savings by determining the direction of airflow and calculating the occupant-fan distance (Liu et al., 2017). Petersen et al. automatically generated a occupant location information at entrance regions

by using depth camera (Petersen et al., 2016). Wang et al. used multiple cameras to gather real-time images from different angles, providing real-time location for a group of individuals to control the zone-based HVAC system (Wang et al., 2021). Despite the promising results demonstrated by camera-based techniques in prior studies, they are some limitations. Depth cameras proved impractical due to their high costs relative to regular RGB cameras. Moreover, the use of multiple RGB cameras could potentially introduce calibration errors and necessitate installation restrictions as compared to single RGB cameras. Since the accuracy offered by multiple cameras can be improved by obtaining precise data from individual cameras, there arises a necessity for a method that accurately locates a real person using only a single RGB camera. Therefore, this study aims to develop a framework to automatically obtain occupant location information using a single RGB camera.

***2. Methodology*:** This study focuses on obtaining location information of occupants. Toward this end, the world coordinates in indoor environments are estimated from the single RGB image. The framework for estimating the world coordinates of occupants consists of three main steps: (i) depth estimation, (ii) instance segmentation, and (iii) camera calibration and post-processing (refers to Figure 1).

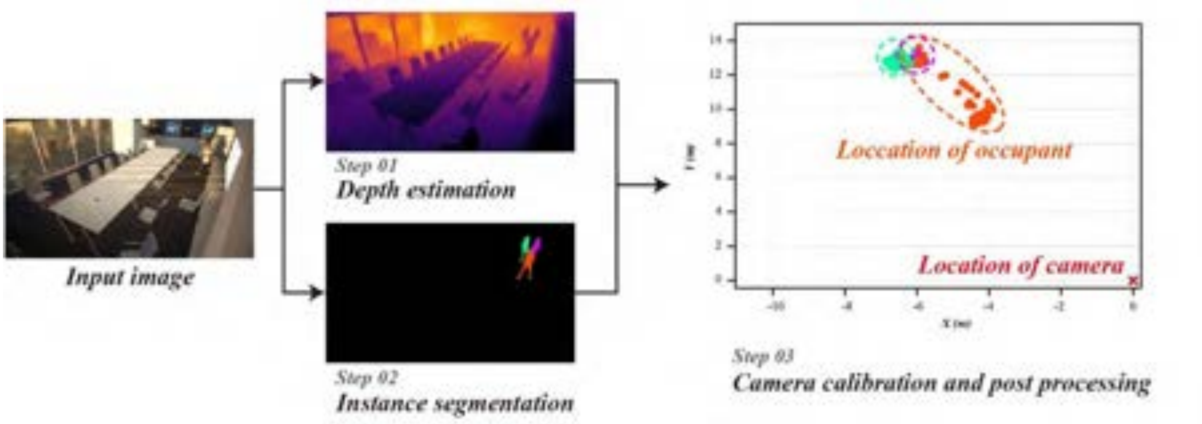

Figure 1. Overall framework for estimating the world coordinates of occupants.

Firstly, the depth estimation model plays a crucial role in obtaining occupant location by estimating depth information or the distance of objects in the scene. Depth estimation provides essential spatial cues necessary for accurately determining the world coordinates of occupants within indoor environments. By estimating depth, the model helps differentiate between objects at varying distances from the camera and facilitates the conversion of 2D image coordinates to 3D world coordinates. In this study, the ZoeDepth model was employed, which demonstrated a high level of accuracy with an error rate of only approximately 2% (Bhat et al., 2023), trained on the New York Depth (NYU Depth v2) dataset (Silberman et al., 2012). This dataset provides synchronized RGB and depth images for 1,449 scenes, encompassing diverse indoor environments with different room layouts, furniture arrangements, and lighting conditions. Therefore, training depth estimation models on this dataset ensures their suitability for indoor environments and yields accurate depth predictions. The depth estimation model takes RGB images as input and outputs a depth map indicating the distance of each pixel from the camera.

Secondly, the instance segmentation model is used to identify and segment individual occupants within captured images. Instance segmentation goes beyond traditional object detection by not only detecting objects but also providing pixel-level segmentation masks that differentiate between different instances of the same object class. By associating each segmented occupant with their corresponding depth values, their precise 3D positions in the indoor environment can be determined. In this study, we utilized the Mask2Former model (Cheng et al., 2022)fine-tuned on the COCO dataset, which demonstrates high performance in the field of instance segmentation (Lin et al., 2014). The COCO dataset covers a wide range of challenging scenarios, including crowded scenes, occlusions, and varying poses. Training on the COCO dataset enhances the model's ability to accurately segment humans in complex real-world situations. The instance segmentation model predicts the pixel-level positions of individuals from RGB images and outputs a mask image for each occupant.

Finally, camera calibration and post-processing are performed to locate occupants in the indoor environments based on the provided mask image and depth map. Camera calibration involves finding the correspondence between pixel coordinates in the image and the real-world coordinates in the scene. This correspondence is expressed in matrix form, as shown in Equation (1). The camera calibration process involves solving for the intrinsic and extrinsic matrices of the camera.

$$s\begin{bmatrix}u\\v\\1\end{bmatrix}=\begin{bmatrix}f_x & 0 & c_x\\0 & f_y & c_y\\0 & 0 & 1\end{bmatrix}\begin{bmatrix}r_{11} & r_{12} & r_{13} & t_x\\r_{21} & r_{22} & r_{23} & t_y\\r_{31} & r_{32} & r_{33} & t_z\end{bmatrix}\begin{bmatrix}X\\Y\\Z\\1\end{bmatrix} \quad (1)$$

where (*X, Y, Z*) represents the world coordinates and (*u, v*) represents the pixel coordinates in the image. The scale vector s is acquired from the depth map that corresponds to the pixel coordinates (u, v). The intrinsic parameters comprise of focal lengths (f_x and f_y) and the principal point (c_x and c_y), which represents the center of the image. On the other hand, the extrinsic parameters include rotation vectors (*r*) and translation vectors (*t*).

The camera calibration process is solving from the camera's intrinsic and extrinsic matrices. These matrices are derived from the mask image, which provides pixel coordinates (*u, v*), and the depth map, which contributes the scale vector s. The camera's intrinsic parameters, specific to each camera, can be established in advance. On the other hand, the extrinsic parameters are obtained from the camera's installation position and orientation. By applying the given formula, the global coordinates (*X, Y, Z*) of the occupants can be extracted. Given that a single mask image comprises multiple points pertaining to one individual, it's crucial to refine these into a singular point to accurately deduce the occupant location. The Interquartile Range method is applied to eliminate outlier coordinates, followed by computing the median values to determine the precise location of each occupant.

3. Case study: The proposed framework for obtaining location information of occupants has been verified in a virtual environment using the Unity game engine (Unity Technologies, 2020). The Unity environment offers the advantage of creating indoor environments that closely resemble real-world settings, while also allowing for accurate data collection by randomly varying the position of the occupants. For evaluation, a simulated meeting room with dimensions of 5m x 10m x 3m was used. A camera was strategically placed in a corner at a height of 2.9m and an angle of 30 degrees to capture the entire space. The occupant's location was randomly assigned within the meeting room, and a total of 100 images were collected, each with its corresponding person's location. The number of occupants in each image ranged from more than one to less than six. Notably, the intrinsic parameters of the camera were determined using the Unity camera's local length, while the principal point was set at the center of the image (960, 540). Additionally, the extrinsic parameters were calculated based on the camera's position (0, 0, 2.9) and angle (30 degrees).

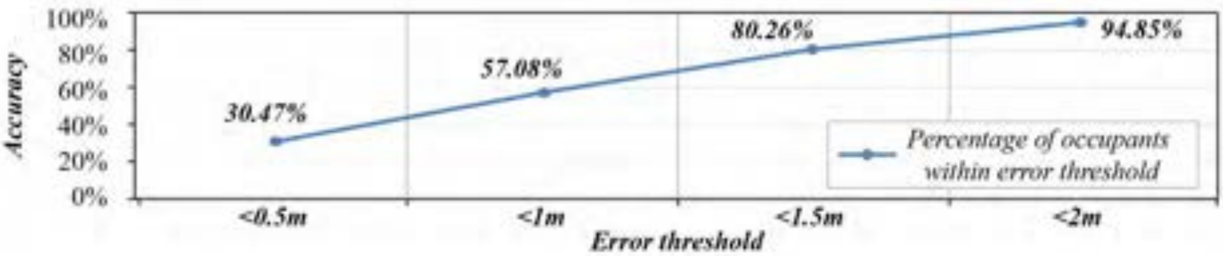

Figure 2. Percentage of occupants within error threshold.

The results revealed an average error of 0.94m with a standard deviation of 0.63m. The percentage of occupants with errors less than 0.5m was relatively low at 30.47%. However, when considering a larger error threshold of 2m, the proportion of occupants within this range was significantly higher at 94.85%. Through analysis, the reason for the errors was found: This is due to the decrease in the depth map's precision when the image resolution inputted into the depth estimation model was downscaled from (1920, 1080) to (512, 384). Nonetheless, in real-world applications, these results can be interpreted as follows: Firstly, in the context of HVAC and lighting systems, which are typically installed at intervals greater than 2m, the precise granularity of location detection may not have substantial practical implications. If these systems can effectively operate with intervals of 2m, the 2m error range remains acceptable while still allowing for satisfactory system performance. This can be further optimized by adjusting the spatial arrangement of HVAC and lighting systems to align with the accuracy of the occupancy detection system. Secondly, when considering zone control capabilities, larger spaces are often divided into zones. If a single zone is larger than the error range, the system's accuracy proves sufficient. Even with a 2m error range, the system should be capable of accurately identifying the specific zone that an occupant is in, thereby enabling effective control of that zone.

4. Conclusion: The proposed framework can reliably obtain occupant location from a single RGB image within indoor environments, an average positional error of 0.94m. In practical terms, this level of error is acceptable, especially when considering the typical arrangement of HVAC and lighting systems for zoning control. The research thereby contributes to the development of energy-efficient strategies for building management, paving the way for considerable energy savings in HVAC and lighting operations by precisely controlling unoccupied areas.

Acknowledgements

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References:

Andrews, J., Kowsika, M., Vakil, A., & Li, J. (2020). A Motion Induced Passive Infrared (PIR) Sensor for Stationary Human Occupancy Detection. 2020 IEEE/ION Position, Location and Navigation Symposium, PLANS 2020. https://doi.org/10.1109/PLANS46316.2020.9109909

Bhat, S. F., Birkl, R., Wofk, D., Wonka, P., & Müller, M. (2023). ZoeDepth: Zero-shot Transfer by Combining Relative and Metric Depth.

Chen, Z., Jiang, C., & Xie, L. (2018). Building occupancy estimation and detection: A review. In Energy and Buildings (Vol. 169). https://doi.org/10.1016/j.enbuild.2018.03.084

Cheng, B., Misra, I., Schwing, A. G., Kirillov, A., & Girdhar, R. (2022). Masked-attention Mask Transformer for Universal Image Segmentation. Proceedings of the IEEE Computer Society Conference on Computer Vision and Pattern Recognition, 2022-June. https://doi.org/10.1109/CVPR52688.2022.00135

Chun, S. Y., Lee, C. S., & Jang, J. S. (2015). Real-time smart lighting control using human motion tracking from depth camera. Journal of Real-Time Image Processing, 10(4). https://doi.org/10.1007/s11554-014-0414-1

Lin, T. Y., Maire, M., Belongie, S., Hays, J., Perona, P., Ramanan, D., Dollár, P., & Zitnick, C. L. (2014). Microsoft COCO: Common objects in context. Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 8693 LNCS(PART 5). https://doi.org/10.1007/978-3-319-10602-1_48

Liu, S., Yin, L., Ho, W. K., Ling, K. V., & Schiavon, S. (2017). A tracking cooling fan using geofence and camera-based indoor localization. Building and Environment, 114. https://doi.org/10.1016/j.buildenv.2016.11.047

Petersen, S., Pedersen, T. H., Nielsen, K. U., & Knudsen, M. D. (2016). Establishing an image-based ground truth for validation of sensor data-based room occupancy detection. Energy and Buildings, 130. https://doi.org/10.1016/j.enbuild.2016.09.009

Schiavon, S., Melikov, A. K., & Sekhar, C. (2010). Energy analysis of the personalized ventilation system in hot and humid climates. Energy and Buildings, 42(5). https://doi.org/10.1016/j.enbuild.2009.11.009

Silberman, N., Hoiem, D., Kohli, P., & Fergus, R. (2012). Indoor segmentation and support inference from RGBD images. Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 7576 LNCS(PART 5). https://doi.org/10.1007/978-3-642-33715-4_54

Tekler, Z. D., Low, R., Gunay, B., Andersen, R. K., & Blessing, L. (2020). A scalable Bluetooth Low Energy approach to identify occupancy patterns and profiles in office spaces. Building and Environment, 171. https://doi.org/10.1016/j.buildenv.2020.106681

Unity Technologies. (2020). Unity Perception Package.

Wang, H., Wang, G., & Li, X. (2021). Image-based occupancy positioning system using pose-estimation model for demand-oriented ventilation. Journal of Building Engineering, 39. https://doi.org/10.1016/j.jobe.2021.102220

Yau, Y. H., & Hasbi, S. (2013). A review of climate change impacts on commercial buildings and their technical services in the tropics. In Renewable and Sustainable Energy Reviews (Vol. 18). https://doi.org/10.1016/j.rser.2012.10.035

Sustainable solutions under climate change towards water and energy independence using wind power and hydrogen storage

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Keywords: climate change, HRES, wind farms, hydrogen storage, water resources management, sustainable development

ABSTRACT

The access to clean fresh water is a matter of major importance for human survival. As the population grows and environmental problems from climate change intensify, access to fresh water is expected to decrease in the foreseeable future (Pichel et al., 2019). A large percentage of natural disasters are related to the availability of water resources and simultaneously affect their availability. Climate change is inextricably linked to the water cycle and therefore affects its availability (Kushawaha et al., 2021). The rise in sea level will increase groundwater salinity in coastal areas and will lead to the depletion of groundwater and to salinization problems (Eswar et al., 2021). At the same time, based on the forecasts, a deterioration of the climatic factors affecting the primary agricultural sector is expected (Anderson et al., 2020). As a general prediction, it is estimated that the length of the cultivation season and consequently agricultural production will decrease. The Water-Energy- Food Index (WEF) highlights the interdependence of water, energy, and food together to the achievement of social stability and economic growth (David et al., 2022). In addition, the availability of water resources may have an impact on the capacity to generate electricity to meet energy demands (Nouri et al., 2019).

Water scarcity and energy independence are two critical issues facing many Greek islands, with limited access to energy sources and to freshwater. Today, the average annual cost for the transportation of freshwater to the islands from the mainland has been estimated at around 8.2 €/m^3 (Myronidis et al., 2021). Also, the fulfillment of their energy requirements through Local Power Stations (LPS) leads to high-cost electricity generation, blackouts during summer which is a high-energy demand period due to tourism, dependence on conventional fuels and unstable network performance. In recent years, Hybrid Renewable Energy Systems (HRES) would be the solution to energy dependence and water scarcity of these islands. HRESs combine one or more renewable energy sources (RES), such as wind, solar, and hydroelectric power, with one or more storage technologies. This integration of Renewable Energy Sources (RES) units and energy storage systems can solve the problems from the stochastic nature of natural variables, especially the wind and solar potential, can contribute to RES transition, can improve the WEF nexus, can enhance the network reliability and performance and can reduce CO_2 emissions. In 2022, renewables prevented over 230 million tonnes of greenhouse gas emissions, according to the Environmental Protection Agency of the United States and this is equivalent to 49 million petrol-powered cars off the road for one year. With the integration of a desalination unit into an HRES, the problem of lack of domestic and irrigation water is also solved through the desalination of the abundant sea water that surrounds these islands.

In the present research study, an energy management scenario for an HRES consisting of a wind farm, a desalination unit and a hydrogen storage unit for the excess produced RES from the wind turbines, is developed. The fulfillment of domestic and irrigation water demand and the fulfillment of household energy consumption is the main purpose of the proposed methodology. The nominal power of the wind farm is estimated according to Kaldellis et al. (2001). The hydrogen tank is dimensioned for two days of autonomy (Bhandari et al., 2015). The fuel cell should be able to handle any electrical load that cannot be met by the wind farm, while the electrolyzer should be able to convert any surplus energy into hydrogen at each time step (Ceran et al., 2021). The desalination unit is supposed to be able to cover the average demand for desalinated domestic and irrigation water. Also, the desalination unit is used for the

desalination of the seawater that is used by the electrolyzer for the production of green hydrogen. The study area is Fournoi Korseon, an island in the South-East Aegean Sea. The permanent population of the island is provided by Hellenic Statistical Authority and is 1400 residents. However, as the island is a popular tourist destination, the fluctuates significantly depending on the time of year. According to the Technical Service of the island, the population reaches 4000 during summer and especially in August, which is the month with the most tourist traffic in the Greek islands. Data about wind speed, temperature and precipitation are obtained from the weather station of Fournoi Korseon of the National Observatory of Athens Automatic Network-NOANN (Lagouvardos et al., 2017). Wind speed is used for the estimation of the produced energy from the wind farm, according to the power curve, while temperature and precipitation are used for the estimation of irrigation water demand, according to the Blaney-Criddle method (Blaney HF & Criddle WD, 1962) for the calculation of evapotranspiration. For irrigation water demand, the crops of the islands are obtained from the Hellenic Statistical Authority. Domestic water requirements are provided are estimated according to the monthly population. Data about electric load are provided by the Public Power Corporation (PPC).

The simulations are conducted in an hourly time step and for wind data of 25 years, as this period is the lifetime of the whole project. Wind speed is characterized by its intermittent nature and high seasonality and, also, according to a sensitivity analysis conducted by Bertsiou and Baltas (2022) to a similar HRES, wind speed is the meteorological parameter that affects more the final results. The production of synthetic wind speed time-series is based on the methodology of Negra et al. (2008), as it is of high importance for the wind speed to maintain its hourly variation and monthly seasonality. For every time step, for the 25 years of wind data the produced energy from the wind farm is calculated and the demand for domestic water, irrigation water and electricity are calculated too. After the fulfillment of the demands with the same order of priority, it is checked if there is an energy surplus or energy deficit. If there is an energy surplus it is checked if there is available space in the hydrogen tank for storage. If there is an energy deficit it is checked if there is available hydrogen stored in the hydrogen tank. After each time step the met and unmet demands are calculated. Results about the Loss of Load Probability (LOLP) and the final price of energy and desalinated water are extracted for the whole lifetime of the project. Also, results about the reduced CO_2 emissions and the amount saved from the Emissions Trading System due to the integration of the HRES to the island are presented. It is found that, although results differ throughout the whole lifetime of the project, the cost of desalinated water is significantly reduced, compared to current prices, the amount of avoided emissions is noteworthy. Also, following the same coverage priority order, such projects can contribute over 85% of the whole domestic water demands, 80% of the whole domestic water demands and over 72% of the whole electrical demands.

References:

Anderson, R., Bayer, P. E., Edwards, D. 2020. Climate change and the need for agricultural adaptation. Current opinion in plant biology, 56, 197-202, https://doi.org/10.1016/j.pbi.2019.12.006.

Bertsiou, M.M., Baltas, E. 2022. Power to Hydrogen and Power to Water Using Wind Energy. Wind, 2(2), 305-324, https://doi.org/10.3390/wind2020017.

Bhandari, B., Lee, K.T., Lee, G.Y., Cho, Y.M., Ahn, S.H. 2015. Optimization of hybrid renewable energy power systems: A review. International Journal of Precision Engineering and Manufacturing-Green Technology, 2(1), 99–112, https://doi.org/10.1007/s40684-015-0013-z.

Blaney, H.F., Criddle, W.D. 1962. Determining consumptive use and irrigation water requirements (No. 1275). Us Department of Agriculture.

Ceran, B., Mielcarek, A., Hassan, Q., Teneta, J., Jaszczur, M. 2021. Aging effects on modelling and operation of a photovoltaic system with hydrogen storage. Applied Energy, 297, 117161, https://doi.org/10.1016/j.apenergy.2021.117161.

David, L.O., Nwulu, N.I., Aigbavboa, C.O., Adepoju, O.O. 2022. Integrating fourth industrial revolution (4IR) technologies into the water, energy & food nexus for sustainable security: A bibliometric analysis. Journal of Cleaner Production, 363, 132522, https://doi.org/10.1016/j.jclepro.2022.132522.

Eswar, D., Karuppusamy, R., Chellamuthu, S. 2021. Drivers of soil salinity and their correlation with climate change. Current Opinion in Environmental Sustainability, 50, 310-318, https://doi.org/10.1016/j.cosust.2020.10.015.

Kaldellis, J.K., Kavadias, K., Christinakis, E. 2001. Evaluation of the wind–hydro energy solution for remote islands. Energy Conversion and Management, 42(9), 1105–1120, https://doi.org/10.1016/S0196-8904(00)00125-4.

Kushawaha, J., Borra, S., Kushawaha, A.K., Singh, G., Singh, P. 2021. Climate change and its impact on natural resources. In Water conservation in the era of global climate change, 333-346, Elsevier, https://doi.org/10.1016/B978-0-12-820200-5.00002-6.

Lagouvardos, K., Kotroni, V., Bezes, A., Koletsis, I., Kopania, T., Lykoudis, S., Mazarakis, N., Papagiannaki, K., Vougioukas, S. 2017. The automatic weather stations NOANN network of the National Observatory of Athens: operation and database. Geoscience Data Journal, 4(1), 4–16, https://doi.org/10.1002/gdj3.44.

Myronidis, D., Nikolaos, T. 2021. Changes in climatic patterns and tourism and their concomitant effect on drinking water transfers into the region of South Aegean, Greece. Stochastic Environmental Research and Risk Assessment, 35(9), 1725-1739, https://doi.org/10.1007/s00477-021-02015-y.

Negra, NB., Holmstrøm, O., Bak-Jensen, B., Sørensen, P. 2008. Model of a synthetic wind speed time series generator. Wind Energy: An International Journal for Progress and Applications in Wind Power Conversion Technology, 11(2), 193-209, https://doi.org/10.1002/we.244.

Nouri, N., Balali, F., Nasiri, A., Seifoddini, H., Otieno, W. 2019. Water withdrawal and consumption reduction for electrical energy generation systems. Applied Energy, 248, 196–206, https://doi.org/10.1016/j.apenergy.2019.04.023.

Pichel, N., Vivar, M., Fuentes, M. 2019. The problem of drinking water access: A review of disinfection technologies with an emphasis on solar treatment methods. Chemosphere, 218, 1014-1030, https://doi.org/10.1016/j.chemosphere.2018.11.205.

Design and implementation of a solar thermal system as a contribution to resilience and sustainable development in paramo ecosystems

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Keywords: energy transition, space heating, hot water, solar energy, energy saving

ABSTRACT

The use of solar thermal energy for hot water supply or heating is usually achieved by installing solar thermal energy storage systems (STESS). These STESS operate at temperatures between 20° C and 80° C depending on heat demand, technology and ambient conditions. In order to increase the efficiency of the STESS, heat storage materials are used. This allows both the utilization of maximum solar radiation peaks as well as the supply of heat even at night. Heat storage can be implemented as sensible heat or latent heat, but the latter is preferred because of the higher heat densities. For heat storage as latent heat (LHTSS), phase change materials (PCM) are used. For safety and design issues, low-cost, abundant, solid-to-liquid state materials with high enthalpies of fusion and high heat capacities are preferred (Shukla, 2020). Currently, the most commonly used phase change material is paraffine wax of petrochemical origin. Although some renewable PCMs, mainly fatty acids and sugars, have been investigated, some technical disadvantages, but mainly their cost, have prevented their mass application (Yuan, 2014). Colombia is currently the largest producer of palm oil in the Americas, which provides an availability of products and by-products of this industry. One of these by-products is palm stearin, which is composed mainly of saturated fatty acids. In the present work, the enthalpies and temperatures of fusion and crystallization and the solid and liquid heat capacities of soybean soapstock, palm stearin and hydrogenated palm stearin were measured by differential scanning calorimetry. The thermal performance of each material was evaluated under a theoretical scenario by calculating the amount of energy stored when heated from 25 °C to 85 °C, with the aim of using them as PCMs in STESS. Hydrogenated palm stearin achieved the highest heat storage capacity (270 kJ/kg) at the lowest unit cost of COP 38/kJ. These results were the basis for the design and construction of a solar thermal storage system (STSs) which was installed in a Colombian paramo with an altitude of 3,200 meters above sea level (m.a.s.l.) to supply hot water and space heating for a bedroom. This experimental setup implements hydrogenated palm stearin as phase change material (PCM) of renewable origin and a robust measurement and control system, including 39 PT-100 type temperature sensors and a control system based on the microcontroller board Arduino MEGA. This configuration also allows for the implementation of a remote monitoring system. The constructed STSs employs 140 collector tubes and 550 kg of PCM, running at a maximum temperature of 75 °C. The research outcomes so far show that the technology developed can fulfill the energy needs of a rural house in a moorland zone, and it becomes a starting point for designing of systems aimed at other applications or larger scales while diversifying the oil palm value chain, reducing manufacturing costs of thermal energy storage systems and promoting the implementation of solar thermal energy technologies.

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References:

Shukla, A., Sharma, A., Henry Biwolé, P. (2020). Latent Heat-Based Thermal Energy Storage Systems (A. Shukla, A. Sharma, & P. H. Biwolé, Eds.). Apple Academic Press

Yuan, Y., Zhang, N., Tao, W., Cao, X., He, Y. (2014). Fatty acids as phase change materials: A review. Renewable and Sustainable Energy Reviews, 29, 482–498

Recovery of bioenergy and high added value bioproducts from confectionary industrial wastewaters

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Keywords: industrial wastewaters, biohydrogen, VFAs, circular economy

ABSTRACT

For many decades economic development has been based on a linear model consisting of the steps produce – process – consume – discard. The result is that Western societies, due to the thoughtless production and overconsumption of goods, are increasingly depleting natural resources. At the same time, they produce huge amounts of wastes and wastewaters, the accumulation of which leads to the severe degradation of the natural environment. Understanding, however, the consequences of such a production and consumption culture in Europe, has led the European Commission to propose in December 2015 a package of measures aiming at facilitating the transition from a linear to a circular economy. Circular economy is based on the reuse of wastes and wastewaters produced at different stages of the production process of goods, not only through recycling but also through their transformation into other useful products. Thus, wastes/wastewaters are not treated as disposables but as an alternative and valuable source of raw materials, through their reintegration into the cycle of the production chain.

In this light, the current study focuses on the exploitation of a wastewater (WW) that is generated from a large confectionary industry of Western Greece, towards a gaseous energy carrier with high energy density i.e. biohydrogen (H_2) and also different organics acids of high added value i.e. volatile fatty acids (VFAs) and lactic acid (LA), via anaerobic dark fermentation (DF). The wastewater was actually the residues that remain on the cauldrons during the production process of fruit jellies and syrups and which are removed by rinsing with hot water, and it contained mainly sugars but also considerable amount of protein derived from the gelatin of the jelly residues. For the biotransormation of the above to H_2 , VFAs and LA, a mesophilic bioreactor with working volume 0.5L, operated at continuous mode (i.e. as continuous stirred tank reactor, CSTR) was used and the effect of hydraulic retention time (HRT) on the yields of the bioproducts was investigated. For the start-up of the bioreactor the WW was diluted with tap water to initial substrate concentration (S_o) in terms of dissolved chemical oxygen demand d-(COD), 20g/L mixed with heat-shocked anaerobic sludge as inoculum and incubation for 24h at 35.5 °C followed. The transition to continuous operation mode followed, upon checking the hydrogen content of the gas phase, with feed substrate concentration (S_f), 20 g/L and initial HRT 12h. Upon reaching a steady state the HRT was altered as following: 24h, 18h, 24h, 30h and finally 36h.

In **Figure 1** the change of molecular hydrogen ratio in the gas phase of the bioreactor as well as the production rates of biogas and molecular hydrogen during the operation of the CSTR are presented. As shown, the production of gaseous metabolites, H_2 and CO_2 were significantly affected by the alterations of HRT.

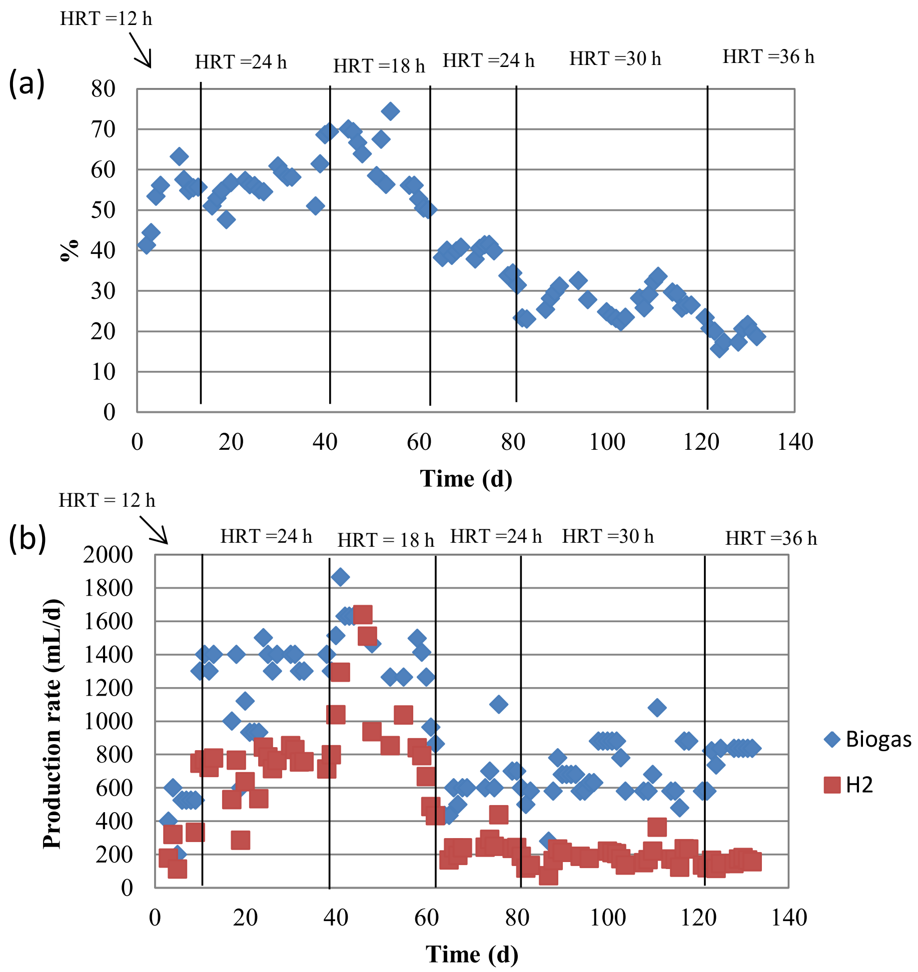

Figure1: Percentage of H_2 in the produced biogas (a), and biogas and H_2 production rates (b) throughout the operation of the CSTR treating confectionary industrial WW from with different HRTs.

Specifically, at the beginning of the continuous operation of the system with HRT, 12h, although the percentage of H_2 showed an increasing trend (from 40% to 60%) in the gas phase, the gas production is generally low, which can be attributed to a possible kinetic limitation of the system since the consumption of sugars is also low (results not shown) with a tendency to be accumulate in the bioreactor. The increase in the HRT at 24h appeared to improve the fermentation capacity of the supplied sugars, with a significant increase in the biogas production rate, without, however, a corresponding increase in the hydrogen production rate. The maximum hydrogen productivity was observed during the operation of the system with 18h HRT, which, however, could not be maintained to achieve a steady state due to the accumulation of solids in the system and the subsequent drop in gas production rates when resuming the 24h HRT operation. This observation could be attributed to a change in the composition of the microbial consortium. The hydrogen production was also low during the operation of the system with higher HRTs, 30h and 36h.

In **Figure 2** the change in the concentrations of the produced VFAs throughout the operation of the CSTR as well as the distribution of all soluble metabolic products, including LA and ethanol in the steady states of the system, are illustrated. As shown, the production of soluble metabolic products is also significantly affected by the HRTs, while it is noteworthy that when the HRT is restored at 24h after 18h, the distribution is significantly differentiated, strengthening the original hypothesis for the prevalence of different microorganisms. This assumption is also supported by the change in the concentration of LA in the steady states which is decreasing during the system operation.

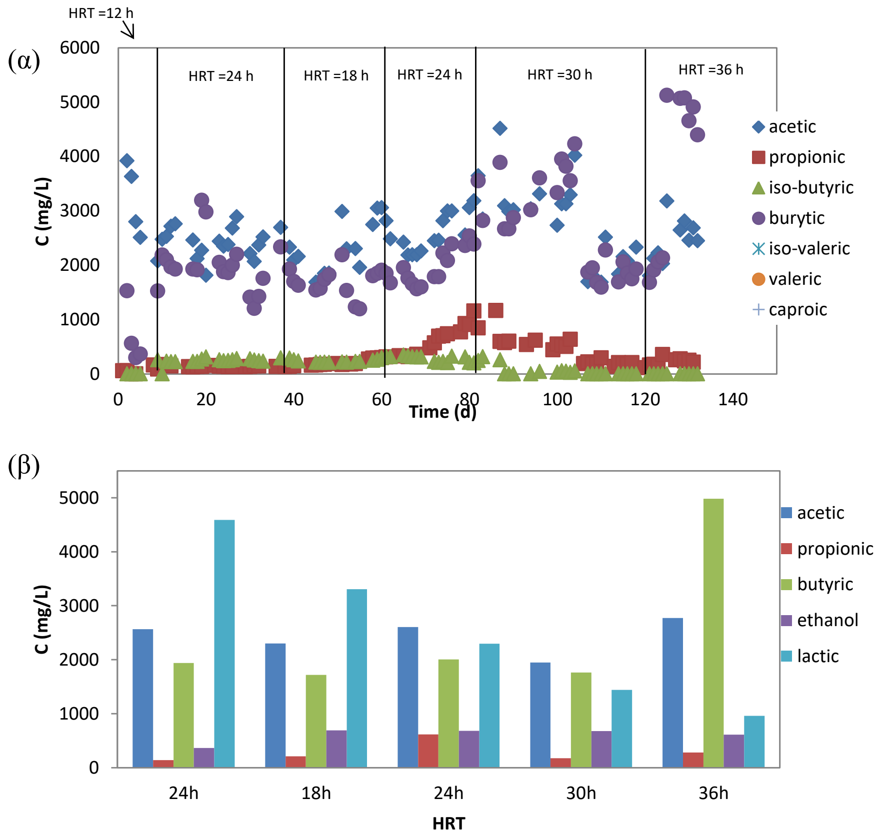

Figure 2: Change in VFAs concentration throughout the operation of the CSTR (a), and distribution of the main soluble metabolic products in the steady states (b).

Table 1 summarizes the yields and productivities of the system in terms of biogas, H_2 and the acidification of the waste to VFAs, for all HRTs tested but for HRT12 during the operational period of which no steady state was achieved due to sugars accumulation.. As shown the maximum yield of H_2 from the waste but also the maximum H_2 molecular yield from the consumed sugars was observed for the lowest HRT, 18h. However, for HRT 18h the acidification rate was the lowest observed, >40%. On the contrary, for the highest, 36h, the lowest H_2 yield was observed with maximum though of acidification, exceeding 70%.

Table 1. Cumulative results of operation of the pilot system of acidification of expired juices in the permanent conditions.

	HRT24	HRT18	HRT24	HRT30	HRT36
Biogas, L/L.d	3.45±0.19	3.52±0.31	1.61±0.13	1.83±0.43	2.09±0.01
H_2 , L/L.d	1.91±0.12	2.19±0.13	0.63±0.55	2.28±0.54	2.19±0.13
Y_{H2}, mL/kg WW	93.90±5.99	76.67±4.54	30.95±2.71	31.08±5.56	29.97±3.50
Y_{H2}^{mol}, mol/mol consumed sugars	0.79±0.02	1.04±0.04	0.51±0.08	0.29±0.04	0.15±0.01
% acidification, VFAs (g COD)/g d-COD initial	41.57±5.01	37.33±2.18	45.36±3.02	28.21±1.36	71.08±0.15

Concluding, it can be noted although during the DF of the WW, the maximum productivity in H_2 is not followed by its maximum acidification, by adjusting the operating conditions of the CSTR, the system can be directed towards the maximum production of different products upon demand valorizing in any case the WW.

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Coupling retired electric vehicle batteries with PV systems for urban sustainability: the case study of Greece

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Keywords: E-waste, Lithium-ion Batteries, Electric Vehicles; Photovoltaic installations; Forecasting; Circular Economy

ABSTRACT

The rapid popularization of electric vehicles (EVs) in the European Union (EU) is creating a new category of e-waste, the lithium-ion batteries (LIBs). LIBs manufacturing involves many raw materials, some of which are Critical Raw Materials (CRMs) for the EU, so their proper management through circular economy (CE) models is essential. These models include Remanufacturing, Reuse and Recycling of LIBs (Wrålsen et al., 2021; Kastanaki and Giannis, 2023).

In this work, the dynamic estimation of retired LIBs from EVs in Greece is accomplished using material flow analysis with a 3-parameter Weibull distribution function under two LIBs lifetime scenarios. The methodology flowchart is shown in Fig. 1. Remanufacturing, Reuse and Recycling of LIBs are considered and all flows are estimated. The trends in future battery chemistries and the dynamic change in specific energy of Battery Electric Vehicles (BEVs) and Plug-In Hybrid Electric Vehicles (PHEVs) are taken into account. The sales of new EVs until 2030 in Greece are considered according to the national policy for promoting electromobility. Among the CE models for retired LIBs, special focus is given on Reuse. Retired batteries hold about 80 % of their initial capacity and can be utilized for applications such as Energy Stationary Storage (ESS) (Rallo et al., 2020; Kotak et al., 2021). Optimized management of retired batteries requires regional planning at country level to reduce logistics costs. This study examines whether the LIBs available for reuse in Greece can meet the demand for ESS for PV installations. It is estimated that by 2030 the accumulated battery capacity available for a second life in Greece will be 0.08-0.14 GWh, covering 2-3.7% of the ESS needed, while by 2035 the battery capacity will be 0.39-0.76 GWh, covering 10.1-19.7% of the required ESS needs.

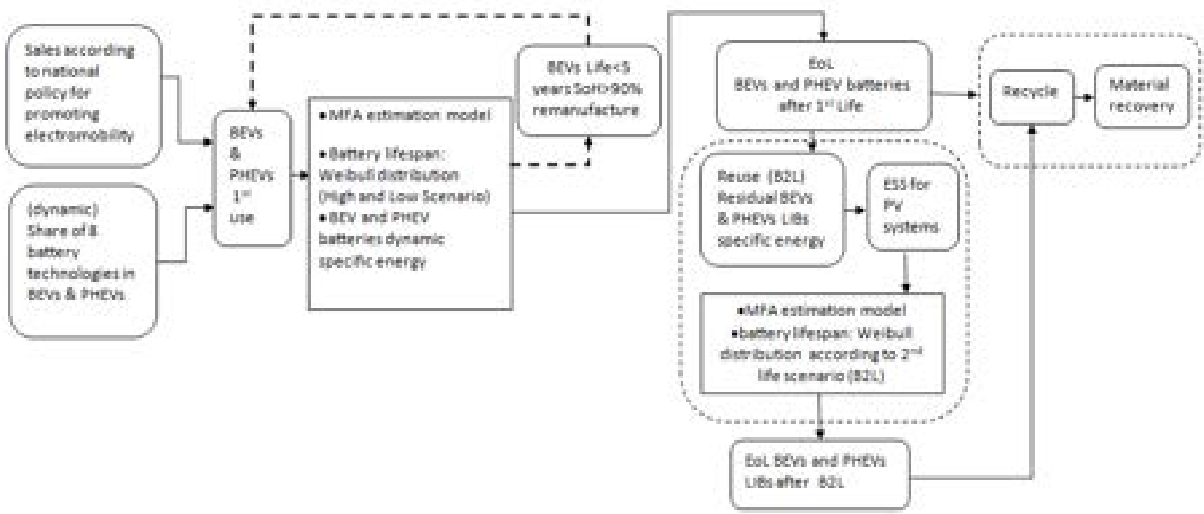

Fig. 1. Methodology flowchart (BEVs: Battery Electric Vehicles; PHEVs Plug-In Hybrid Electric Vehicles; MFA: Material Flow Analysis; B2L: Battery 2nd Life; B2R: Batteries to Recycle; ESS: energy stationary storage)

References:

Kastanaki and Giannis, 2023. Dynamic estimation of end-of-life electric vehicle batteries in the EU-27 considering reuse, remanufacturing and recycling options. J. Clean. Prod., 393, 136349. doi.org/10.1016/j.jclepro.2023.136349

Renewable resources in the conditions of the Slovak Republic

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Keywords: Renewable resources, energy, economic growth, environment, Slovak Republic

ABSTRACT

The work deals with the amount of energy produced from renewable energy sources in the Slovak Republic and their impact on economic growth and the price of electricity. The work also describes the relationships between the amount of energy from renewable sources and economic growth and between the amount of energy from renewable sources and the price of electricity and examines these relationships in the conditions of the Slovak Republic. Renewable energy sources are one of the most dynamic segments of the Slovak energy industry. The work will also deal with the problems and obstacles that stand in the way of introducing or increasing the utilization of the available potential of renewable resources in the Slovak Republic. It investigates the causes and reasons for persistent barriers in the area of legislative support or other political aspects, in the area of economic impacts, technological capability, awareness of the parties concerned, or the possibility of introducing renewable resource technologies, considering the environmental impacts.

Today, climate change is occurring faster than ever before. The constant growth of the population at an unbearable pace is related to the requirement to ensure a dignified life for everyone, which consists of a roof over the head, access to energy, food, but also the availability of all the products listed on the market. Factories are spewing enormous emissions of carbon dioxide into the air they are increasing their production to ensure access to their products for everyone. This pace is unbearable even for our planet, which is constantly showing us those negative effects. There are various natural disasters that have no parallels. The average temperature on the planet is increasing, glaciers are melting and the weather as we know it has changed. In order to secure housing and food, forested areas are deforested and replaced by fields or building plots. The planet is overheating and people are aware of it. 84% of energy consumption is covered by imports, while its domestic production consists primarily of nuclear power plants or solid fuels. Renewable energy sources are natural resources that renew themselves naturally, namely sunlight, wind, water currents, sea waves and geothermal heat. Technologies of renewable energy sources make it possible to transform these sources into electricity, heat and biofuels. The threat of a lack of traditional fuels in the future, as well as the growing interest in environmental protection gives more and more real scope for their use. Recently, there is a tendency to protect the environment and more and more emphasis is being placed on it. People, especially in developed countries, are starting to think more ecologically. They separate waste and also try to reduce the amount of waste they produce, they use environmentally friendly products and try to switch to renewable energy sources.

Widespread public support for renewable energy is justified for environmental and socioeconomic reasons. On the one hand, energy production from renewable energy sources pollutes less than production from traditional fuel sources, and thus prevents the occurrence of negative environmental externalities. Energy from renewable sources thus contributes to the achievement of the goals of the Kyoto Protocol regarding the mitigation of climate change by reducing pollutant emissions. In addition to environmental benefits, renewable energy also offers several socioeconomic benefits, including diversification of energy supply, support for regional and rural development, creation of domestic industry and job opportunities.

The work is characterized by the current situation with renewable resources in the European Union and the Slovak Republic. We also described theoretical foundations of the relationship between the amount of energy produced from renewable sources and economic growth and between the amount of energy produced from renewable sources and the price of electricity.

A national action plan has been established for the Slovak Republic, which is based on Directive 2009/28/EC of the European Parliament and the Council on the promotion of the use of energy from renewable sources, which was adopted on April 23, 2009. It set a goal for the Slovak Republic to achieve in 2020 at least 14% share of energy from renewable sources in gross final energy consumption and at least 10% share of energy from renewable sources in transport in 2020. The National Action Plan of the Slovak Republic for energy from renewable sources drawn up by the government, specifically the Ministry of Economy (2015) contains procedure and measures to achieve this goal. It is compiled in accordance with the State Energy Concept to fulfill the required objectives of the directive for the Slovak Republic and fulfill the regulatory function of energy operational support. The national action plan even foresees exceeding the goal, namely the achievement of a 16.2% share of energy from renewable sources in gross final energy consumption in 2020. Achieving this goal is based on investment support within state support programs and structural funds using financial resources of the European Union and on operational support for electricity production resulting from the Act on Supported Energy Sources. The National Action Plan of the Slovak Republic for Energy from Renewable Sources (2015) describes financial support for renewable energy sources in the Slovak Republic, which takes several forms:

- Investment support from subsidy programs to support the production of electricity and heat from renewable sources:
  - ✓ State programs
  - ✓ Operating programs.
- Payments for purchase prices and green bonuses for supporting the production of electricity from renewable sources (operational form of support). The problem is that this support is subject to a 20% value added tax.
- Exemption, reduction or refund of taxes:
  - ✓ Tax depreciation.
  - ✓ Exemption from electricity tax for electricity from renewable sources with a power of up to 30 kW of installed power consumed directly by the producer.
- Exemption from real estate tax:
  - ✓ Projects of renewable energy sources, as long as the land forms one functional unit with buildings serving exclusively for the purpose of improving the environment,
  - ✓ Buildings exclusively serving the operation of renewable energy sources, with the exception of solar energy and real estate after changing the heating system from solid fuels to a system using renewable energy sources.

The action plan sets out the national goals of the Slovak Republic for the share of energy from renewable sources consumed in the transport, electricity production and heat and cold production sectors in 2020, the trajectories of the expected growth in the use of renewable energy sources in individual sectors in the years 2010-2020, measures to achieve the goals, support systems as well as the overall expected contribution of the measures of individual energy production technologies from RES and in the area of efficiency and energy saving to the achievement of binding goals. The overall national target is to increase the use of renewable energy sources in proportion to gross final energy consumption from 6.7% in 2005 to 14% in 2020, which represents 1,572 ktoe (66 PJ) of energy from renewable energy sources in 2020.

Sector goals for 2020:

- Electricity production 24%.
- Heat and cold production 14.6%.

- Shipping 10%.

Acknowledgements
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References:

European Commission, GDP and main components. In: Eurostat. Luxembourg. https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=namq_10_gdp&lang=en

European Parliament and Council of the European Union. 2018

European parliament, council OF THE EUROPEAN UNION. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, 23 April 2009, OJ L 140, 5. 6. 2009, p. 16–62 (BG, ES, CS, DA, DE, ET, EL, EN, FR, IT, LV, LT, HU, MT, NL, PL, PT, RO, SK, SL, FI, SV).

Ministry of Economy and Construction of the Slovak Republic, 2010. National action plan for energy from renewable sources In: https://www.mhsr.sk/uploads/files/krFyTZfZ.pdf

Effect of environmental factors on dust accumulation and the efficiency of photovoltaic panels: A study case in an Andean City

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Keywords: Dust, photovoltaic panels, weather variables, energy performance.

1. ABSTRACT

The production of electrical energy from renewable sources around the world reached approximately 23% in 2015 (World Bank, 2023), but it is estimated that this percentage will increase to around 66% by the year 2040. One of the sources with the highest growth is wind and solar energy, which accounted for more than 10% of global energy generation, according to recent data from the World Economic Forum (WEF, 2023). This trend is a result, among other factors, of increasing awareness of the impacts of fossil fuel use and its role in climate change, as well as government incentives for energy conversion, and global investments in research, development, and innovation. This fact has led to technological advancements in the sector as well as a significant reduction in technology costs. Solar photovoltaic energy represents a straightforward process for obtaining energy for users, as the operation is simple and maintenance costs are practically negligible, which has allowed the technology to gain global acceptance and commercial success.

Although photovoltaic panels are distributed globally, not all geographical locations are suitable for installing these systems. Parameters such as air temperature, solar radiation, snow, shade, and dust on their surface can influence the capacity of the equipment to convert solar light into electrical energy. Among these factors, accumulated dust on the panels can significantly impact system performance, depending on the concentration of airborne particles in the atmosphere, which reduces the radiation incident on the panel surface through scattering, reflection, or absorption (Styszko et al., 2019). As a result of this phenomenon, urban areas tend to receive less solar radiation compared to rural or suburban areas.

The dust in the air can deposit more easily with larger particle sizes, higher concentration, shape, and density. It can also be influenced by certain meteorological variables such as relative humidity, air temperature, and precipitation. High relative humidity (>80%) causes high adhesion forces between surfaces and dust (Said et al., 2018), thus favoring its accumulation. On the other hand, wind speed can favor the resuspension of dust and its deposition on the panel surface (Ilse et al., 2018). Precipitation can wash the surface of the panels; however, water droplets can evaporate, leaving a trail of dust on the surface.

The relationship between dust density and panel efficiency has been previously analyzed. In desert biomes, a reduction of 7.6% in panel electrical current and 2% in voltage has been reported for dust densities (DP) of 10 g/m^2 (Hamdi et al., 2018). Under conditions of urban air pollution (Shanghai, China), DP ranged from 2.2 g/m^2 to 30.2 g/m^2, with conversion efficiency losses of 5.3% and 43%, respectively (Wang et al., 2019). Other studies have been published in recent years on large urban areas with similar conclusions (Wang et al., 2020) (Tanesab et al., 2019).

To our knowledge, there is no research focused on understanding the effect of climatic dynamics on dust sedimentation and consequently panel efficiency in tropical high-altitude cities. Cases of studies in the literature include mainly areas with low precipitation and high dust concentration in the atmosphere.

In this context, the present study determined the effect of meteorological variables, including ambient temperature (TAM), wind speed and direction (VV), solar radiation (RS), relative humidity (HR), and

precipitation (PRE), on dust sedimentation and accumulation on the surface of a solar panel and its electrical generation in the environmental conditions of a tropical high-altitude city (Popayán, Cauca, Colombia). Popayán has high values of HR and PRE throughout the year, with significant variations between rainy and dry seasons, and marked presence of El Niño-Southern Oscillation (ENSO) phenomena. Additionally, it has high concentrations of dust due to factors such as high vehicular traffic flow, slow traffic dynamics, steep roads, and outdated vehicle technologies.

In this context, the DP, the short-circuit current (Isc), open-circuit voltage (Voc), conversion efficiency, and accumulated dust density on the panels were analyzed. Additionally, a physicochemical characterization of the deposited dust was conducted, including an approximate analysis of its sources.

1.1 Methodology

Popayán is a city located in the Andes mountain range with an altitude of 1737 meters above sea level. It has a temperate-humid climate, an approximate annual total precipitation of 2121 mm, relative humidity ranging from 70% to 83%, and an average temperature of 18.7 °C.

The experimental system consisted of two solar panels with identical technical specifications, supported on individual wooden bases at an angle of 10° and facing south. Adjacent to this system, a glass sheet was installed, covered with 90 glass plates measuring approximately 9 cm in length, 7 cm in width, and 0.3 cm in thickness (Figure 1), emulating the surface area of the panel.

Figure 1. Experimental system with 2 solar panels, and a glass sheet supporting 90 small plates.

One of the panels (PA) was exposed to natural conditions without any cleaning or maintenance action, aiming to capture the natural sedimentation and dust accumulation, while the other solar panel (PB) served as the reference system since it underwent daily cleaning.

The weight of the deposition of dust was determined using a 0.1 mg sensitivity analytical balance (AND brand, model HR-250A). Each glass plate, one per day, allowed the determination of the dust quantity by subtracting the weight of the plate + dust from the weight of the plate. This weight was divided by the area of the glass plate to determine the dust density (DP). The dust was stored in clean amber glass vials of 15 mL for subsequent physicochemical characterization.

The difference in electrical performance between the two solar panels (PA and PB) was monitored by analyzing the variation in Isc and Voc. These data were measured using two multimeters (Uni-trend technology brand, UT33C+ model) with sensitivities of ± (1.2% + 3) for Voc and ± (1% + 2) for Isc.

A Bruker D8 Advance X-ray Diffractometer for polycrystalline samples was used for mineral characterization. Additionally, physical characterization was performed using a scanning electron microscope (SEM) with an EDAX APOLLO X detector with a resolution of 126.1 eV. The EDX Genesis software was used to interpret the images. The meteorological variables of interest (TAM, HR, PRE, RS, DV, and VV) were obtained using an automated Vantage PRO 2 weather station.

1.2 Results and Discussion

Physical and chemical characterization of dust

The diameter of dust particles is mainly within the range of 2 to 30 µm, accounting for approximately 82% of the total, with high heterogeneity in their shapes. The smaller amount of particles with larger sizes can be explained by their ease of being removed from the panel's surface by strong winds or heavy rainfall (Cordero et al., 2018). This prevalence of smaller sizes could cause wear on the panel surface as they have a higher probability of penetrating the protective layer and accumulating in the spaces of the photovoltaic cells and other components.

The XRD results allowed the identification of a high percentage of inorganic compounds in the sample (86.1%). All of the minerals are silicates, except for calcite and magnesian calcite, which belong to the carbonates. Silicates, as well as calcite, are generally used to control corrosive processes in certain environments, so the chemical composition does not seem a risk to panel wear.

The high percentage of minerals originating from igneous rocks explains that the most likely source of the dust deposited is geological since the rocks in the municipality of Popayán range in age from the Paleozoic to the Quaternary and are mostly igneous. Activities that promote the presence of this type of dust in the area can include resuspension from vehicular traffic, construction activities, brick production in quarries, and extraction of construction materials. The results of EDS confirm the petrogenic origin of the material deposited.

Influence of meteorological variables on the accumulation of dust

The relationship between meteorological variables and dust accumulation was carried out through a principal component análisis (PCA) (Figure 2). Three major groups of related variables were observed in this figure. The first group corresponds to TAM, VV, and RS. The second group corresponds to HR and PRE. The third group corresponds to deposited dust in mass and the density of dust in mass/area.

An increase in TAM is associated with a rise in RS and VV. However, these variables decrease with increasing PRE and HR. This trend is expected since an increase in wind speed leads to reduced cloud cover, which increases solar radiation and, in turn, decreases relative humidity and precipitation. The dust appears to have a weak inverse relationship with the HR/PRE pair. Higher precipitation facilitates the washing of the panel surface, which apparently reduces the accumulation. However, this relationship is not strong under high relative humidity conditions due to the increased weight of suspended particles, favoring sedimentation.

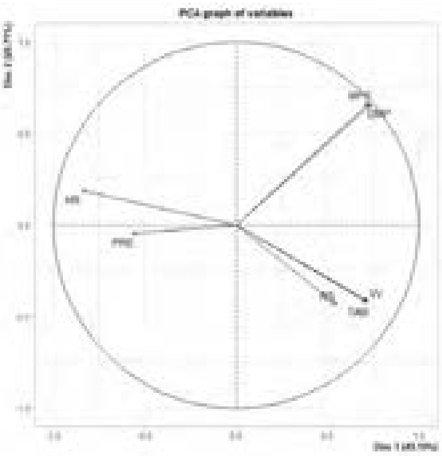

Figure 2. PCA (Principal Component Analysis) for meteorological variables and dust deposited.

Effect of panel dust deposition on electrical parameters

In general, the dust deposition increased linearly during the sampling period. The final dust density was 0.83 g/m^2, with a maximum of 0.93 g/m^2 (Figure 3). This accumulation resulted in a loss of 0.36% in Isc generation, 0.036% in Voc, and 0.39% in energy efficiency for every 0.1 g/m2 of sedimented dust, respectively.

There is a very high positive correlation between Isc losses and dust deposition, with a Spearman's rho of 0.933.

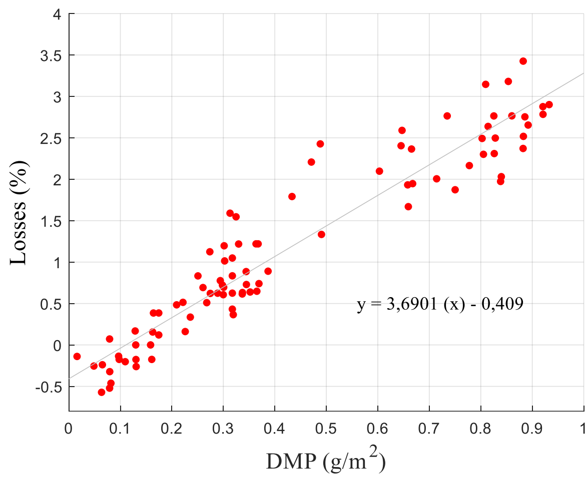

Figure 3. Percentage losses in Isc generation between the dirty panel and the clean panel.

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References:

Cordero, R.R., Damiani, A., Laroze, D., MacDonell, S., Jorquera, J., Sepúlveda, E., Feron, S., Llanillo, P., Labbe, F., Carrasco, J., Ferrer, J., Torres, G., 2018. Effects of soiling on photovoltaic (PV) modules in the Atacama Desert. Sci. Rep. 8. https://doi.org/10.1038/s41598-018-32291-8

Forum, W. economic, n.d. The future of energy [WWW Document]. URL https://es.weforum.org/agenda/2022/04/la-energia-eolica-y-la-solar-generaron-el-10-de-la-electricidad-global-en-2021-una-novedad-mundial/#:~:text=Por primera vez%2C la energía,2021%2C según los últimos datos.

Hamdi, R.T.A., Sanaa, H.H., Chaichan, M.T., Hussein, K.A., 2018. Dust impact on the photovoltaic outcomes. Artic. Int. J. Comput. Appl. Sci. 5, 2399–4509.

Ilse, K.K., Figgis, B.W., Naumann, V., Hagendorf, C., Bagdahn, J., 2018. Fundamentals of soiling processes on photovoltaic modules. Renew. Sustain. Energy Rev. 98, 239–254. https://doi.org/10.1016/j.rser.2018.09.015

Mundial, B., 2023. Producción de energía eléctrica renovable (% de la producción total de electricidad) [WWW Document]. URL https://datos.bancomundial.org/indicator/EG.ELC.RNEW.ZS

Said, S.A.M., Hassan, G., Walwil, H.M., Al-Aqeeli, N., 2018. The effect of environmental factors and dust accumulation on photovoltaic modules and dust-accumulation mitigation strategies. Renew. Sustain. Energy Rev. 82, 743–760. https://doi.org/10.1016/j.rser.2017.09.042

Styszko, K., Jaszczur, M., Teneta, J., Hassan, Q., Burzyńska, P., Marcinek, E., Łopian, N., Samek, L., 2019. An analysis of the dust deposition on solar photovoltaic modules. Environ. Sci. Pollut. Res. 26, 8393–8401. https://doi.org/10.1007/s11356-018-1847-z

Tanesab, J., Parlevliet, D., Whale, J., Urmee, T., 2019. The effect of dust with different morphologies on the performance degradation of photovoltaic modules. Sustain. Energy Technol. Assessments 31, 347–354. https://doi.org/10.1016/j.seta.2018.12.024

Wang, H., Meng, X., Chen, J., 2020. Effect of air quality and dust deposition on power generation performance of photovoltaic module on building roof. Build. Serv. Eng. Res. Technol. 41, 73–85. https://doi.org/10.1177/0143624419868806

Forest conversion and GHG emission in screening and EIA procedures regarding PV systems in Croatia

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Keywords: Dust, photovoltaic panels, weather variables, energy performance.

ABSTRACT

To speed up energy transition, the European Commission proposed to increase the EU's 2030 target for renewable energy, through raising the total renewable energy generation capaci-ties. As part of the process, efforts are also placed so that the permitting procedures for wind farms and solar photovoltaic (PV) systems are speeded up. In addition, the EU Solar Energy Strategy, as part of the REPowerEU aims to bring over 320 GW of newly installed PV systems by the 2025 in EU. According to the European Photovoltaic Industry Association (EPIA) in 2021, EU added 18,2 GW of solar photovoltaics (including rooftop installations).

Similarly, as in the EU, in Croatia during the recent years (2014.-2022.), the growing trend in PV systems is evident from the annual number of requests submitted for screening. In 2022. the number of screening requests peaked, and an increase of 78 % was recorded compared to 2021. Such PV systems up to 100 MWel, according to the Regulation on Environmental Impact Assessment (EIA) (Official Gazette No. 61/14, 03/17), are subjected to the mandatory screening procedure.

Although in several EU member states (such as Germany, France etc.) the EIA processes in-clude the consideration of greenhouse gas (GHG) emissions from natural areas (in this case forests) conversion for building photovoltaic (PV) systems, in Croatia GHG emmisions assessment as regards forest conversion is lacking as part of the EIA procedures. Although in the prescribed legislation (Regulation mentioned above) chapter 2.3. of the Annex V. Criteria on which the decision on the neccesity of EIA report is based, taking into account the ability of the apsorption of the natural environment, including forest areas, in the Screening and EIA Studies the overall GHG balance during the lifetime of the PV systems is based only on a general assumption that the PV system will produce certain amount of GHG emission free electricity, substituting thus such amount of electricity of the national electricity mix produced using traditional, highly GHG emitting fuels such as coal, petrol and gas. In the prescribed legislation (Regulation mentioned above) potential impact on the air quality, climate change, landscape, biodiversity etc. are assessed but the the GHG emissions due to the conversion of natural areas, in this case forests, are not part of the EIA studies. This is also the case for the biggest PV system in Croatia (PV system Promina of 150 MW) that went through the EIA procedure (including the Main assessment for the ecological network) in 2020. and got the positive desicion from the competent authority (Ministry of the Economy and Sustainable Development of the Republic of Croatia) in 2021.

In addition, for screening procedures land conversion is listed as one of the factors that should be taken into account as a prescribed content of the screening report (Annex VII of the Regulation on Environmental Impact Assessment (EIA) (Official Gazette No. 61/14, 03/17), but it is often only expressed as an area ratio that of the current land use that was lost, without taking into account the GHG emissions due to the conversion.

Since ground – mounted PV systems require certain (sometimes even significant) amount of land to be converted, and currently in Croatia GHG emissions from LULUCF in EIA and screen-ing procedures are lacking, we looked at two areas in Croatia (later referred as test areas), both located on the south part of the country, one located on the island of Brač (Splitsko – dalmatinska county) that are dedicated to PV systems deployment and for which screening reports were available on the official website of the competent authority (above-mentioned Ministry) and one on the mainland – Metković (Dubrovačko – neretvanska county). Accord-ing to the on-going EIA and permit related procedures, on the Island of Brač three independ-ent PV systems (power plants) are planned (PV Pelegrin, PV Humac and PV Pučišća) on a

sur-face of nearly 102 hectares. The three PV systems are in different development stages – PV Pelegrin and PV Humac obtained a positive EIA evaluation following the outcome of the screening procedure, while PV Pučišća is still undergoing the screening process. Additionally, for PV Pelegrin location permit is obtained. The mentioned PV systems are located relatively close one to another, occupying similar natural habitats.

PV Metković is planned on a surface of 17 hectares. PV Metković obtained a positive EIA evaluation following the outcome of the screening procedure.

In the test areas we first looked at the screening reports to see if the GHG emissions due to the conversion were considered. Since the beforementioned emission assessment lacked, we tested the relationship between the carbon emissions saved due to the electricity generation from PV systems and carbon emissions released due to the conversion of natural forests and grasslands. Although PV systems don't emit any pollutants during operation, emission from the life cycle of PV systems were considered in the calculations.

For the purposes of this paper, in order to assess the trade offs of the GHG emissions follow-ing a reduction of a pristine habitat, mainly forest an grassland, due to PV system installment, the calculations of natural habitat conversion were made using the program QGIS, and data from the National habitat map for Croatia (2016), Corine land cover (CLC) and publicly availa-ble spatial information from Croatian forestry (national body in charge of the public forests in Croatia). The data was used to calculate the CO2 balance of the PV system considering the natural habitat conversion.

Using the above-mentioned data, it was calculated that if PV systems Pučišća, Humac and Pelegrin are built on the island of Brač, cumulative conversion of the forest land will be about 53,59 hectares. In this area, Mediterranean coniferous forest with predominant Pinus nigra and Pinus halepensis is present. It should be mentioned that due to the natural condi-tions (karst, fires etc.) most of the beforementioned forest is maquis and garrigue. When looking at the PV zone on the island of Brač, it is evident that all three PV systems are also placed on 54,93 hectares (cumulatively) of Mediterranean rocky grasslands as. Cymbopogo-no-Brachypodion ramosi Horvatić 1963), that are due to the abandonment and lack of man-agement under natural progression to woodland, thus in most parts being covered by shrubs of Juniperus genus that are in some parts in form of trees. As regards PV Metković, cumula-tive conversion of the forest land will be about 36,43 hectares. In this area, mixed forest of Quercus ilex and Fraxinus ornus (Fraxino orni-Quercetum ilicis H-ić1956/1958) as well as Quer-cus pubescens and Carpinus orientalis (Querco-Carpinetum orientalis) are present. It should be noted that the carbon sequestration in forest land was not considered, although is thought to be much higher than sequestration in woody biomass, due to the lack of data for Croatia that would enable quantifying this impact.

Both coniferous and deciduous woodlands are known to be effective carbon sinks, and ac-cording to the IPCC guidelines on national greenhouse gas inventories , when all three PV systems (Pučišća, Pelegrin and Humac) are installed the loss in net CO2 emission removal will be -5.543.760 t/CO2 annually, due to the conversion of 53,59 ha of coniferous woodland. When considered that the average duration of PV systems is 30 years, the loss in net CO2 emission removal is – 166.312.800,00 t/CO2 for all 3 above-mentioned PV systems. Addition-ally, when PV Metković is built, the loss in net CO2 emission removal will be – 5.531.250 t/CO2 annually, due to the conversion of 16,26 ha of deciduous woodland. When considering the 30 years average lifespan of PV systems, the total loss in net CO2 emission removal is -165.937.500,00 t/CO2 for the planned PV system Metković.

According to the World Nuclear Association for solar PV 85 tons CO2e/GWh is mean lifecycle GHG emissions. Applying this methodology, the mean lifecycle GHG emissions for all three PV systems (Pučišća, Pelegin and Humac) is 4.848,3 tons of CO2. For PV Metković, the mean lifecycle GHG emissions are 1.530 tons of CO2.

Electricity production from renewable energy sources means savings in emissions of CO2 that would be released from the conventional (non-renewable) sources. According to the DI-RECTIVE 2012/27/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC for production of electric energy CO2 emission is 158,57 t CO_2/GWh i.e kg CO_2/MWh. Considering the above mentioned, if all considered PV systems on the island of Brač (PV Pučišća, Pelegrin and Humac) are installed the sum CO2 emissions savings will be 15.197,79 t CO2/annually. When considering the average lifespan of PV systems (30 years) the total savings add to 455.933,7 t/CO2. For PV Metković the sum CO2 emissions savings will be 2.854,26 t CO2/annually. This adds up to total savings of 85.627,8 t/CO2 for the average lifespan of PV system.

As seen above, there is a trade-off between carbon emissions saved through electricity gen-eration and carbon emissions released due to the conversion of natural forests. This trade-off is -165.861.714,6 t CO2 that will be released due to the conversion of natural forest during the lifespan of the aforementioned three PV systems (Pučišća, Pelegrin and Humac) on the island of Brač, if they are built. Similarly for PV Metković -165.853.402,2 t CO2 will be released due to the conversion.

As seen, the conversion of natural forests for the PV systems will result in a significant loss in net CO2 emission removal. As trade-off between carbon emissions saved through electricity generation and the carbon emissions released due to the conversion of natural forests for PV systems in Croatia are not taken into consideration we highlight the need for a comprehensive assessment of GHG emissions and a balanced approach to ensure the sustainability of renewable energy projects in the EIA procedures.

Implementation of DSS to optimize the selection of marine energy sites on the Mexican coastline

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Keywords: marine energy, environment, circular economy

ABSTRACT

Due to population growth, the adverse effects of climate change and the increase in energy demand, the world is seeking new production models and paradigms. The circular economy principles represent a sustainable production system that can meet multiple goals but poses new challenges. The energy transition is among the circular economy pillars (Khan & Osinska, 2022), and it is of scientific and technological interest to benefit from the ocean energy sources. However, environmental, social, economic and political aspects arise when using the coastal zone.

With this in mind, it is crucial to design analysis tools that help planners integrate all the available information. Among those tools, the Decision Support Systems (DSS) are valuable for planning and decision-making.

Mexico has two coastlines: The Pacific Ocean on the east side and the Gulf of Mexico and the Caribbean Sea on the east side. The coastline is vital for national economic development, where recreational and economic activities occur. In order to minimize the use of conventional fuels and accelerate the energy transition, the potential of marine renewable energy (MRE) to supply energy to coastal populations has been evaluated in recent years.

Methods
In order to understand the functioning of the DSS, a bibliographic search of the elements that compose it, its structure and incorporation in the energy sector was conducted. Subsequently, the factors for structuring a DSS for using MRE in the coastal zone were identified.
Likewise, the valuation of the ecosystem components is required to enrich the analysis of environmental impacts and support the formulation of policies.

Results and discussion
In developing this tool, emphasis is placed on using MRE in areas of high demand. In this case, the relationship between society, tourism and energy demand is a priority. Therefore, the crucial aspect of site selection is related to the potential and availability of the marine energy resource.

The scenarios will provide information on the potential of specific actions to achieve the goals proposed by the decision-maker, incorporating economic valuation to represent the investment needed to carry out the actions. The selected proposals generally focus on the most profitable applications that meet the stakeholders' interests. Therefore, the scenarios can be planned in the short, medium and long term.

References:

Khan, A.M.; Osinska, M. 2022. Energy Consumption under Circular Economy Conditions in the EU Countries. Energies. 15, 7839. https://doi.org/10.3390/en15217839

Zagonari, F. 2008. “An Operative Decision Support System for Integrated Coastal Management: An Application to the Reghaia Lake, Algeria.” (2001): 55–74.

Osmotic Power Generation-Based System for Self-Consumption Electricity

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Keywords: Salinity Gradient, pressure-retarded osmosis,

ABSTRACT

Production and capitalising on renewable energy sources would improve global energy security, reduce the price of conventional fuels and help preserve resources for future generations. Also, greenhouse gas emissions would be reduced, and new employment sources would be created (1, 2, 3, 4).
In general, currently, available techniques for desalination can be used to generate energy from salinity gradients when operated in reverse mode (5). Some of these techniques have been described for energy conversion and grouped into the SGE technologies: pressure-retarded osmosis (PRO), reverse electrodialysis (RED), and utilisation of the vapour-pressure differential (6). PRO is a membrane-based technology investigated and proven more efficient and cost-effective than alternative technologies such as RED (7).
In this PRO process, the osmotic pressure between the low-concentration feed solution and the high-concentration extraction solution drives the pressurised permeation of water through a semi-permeable membrane. An alternative feed for the process is wastewater and brine effluents which would allow the reuse of effluents from municipal and industrial sources. In addition, the effluent has a low environmental impact because it is diluted by the PRO process (7).
In this study, an osmotic power generation scale prototype was designed. The PRO system experiments were performed by simulating hyper-concentrated brines in salt works or near-shore treatment plants. The system comprises two 13.2*14.1*13 cm devices interconnected by a direct osmosis (RO) commercial membrane coupled to two syringes to concentrate the pressure. The results revealed that the increase in flux is positively correlated to the salinity difference. The membrane acted as a filter, helping the retention of salts and desalinating one of the compartments.
The PRO prototype could be connected to existing infrastructure at impacted sites, such as desalination plants and water treatment plants in coastal and island communities as well as providing energy supply and alternative benefits, such as desalinated water, which would reduce greenhouse gas emissions. With PRO's prototype, energy costs would be reduced by providing affordable energy.

References:

1. Nahawand AlZainati, Sudesh Yadav , Ali Altaee , Senthilmurugan Subbiah , Syed Javaid Zaidi , John Zhou , Raed A. Al-Juboori , Yingxue Chen , Mohammad Hasan Shaheed. Impact of hydrodynamic conditions on optimum power generation in dual stage pressure retarded osmosis using spiral-wound membrane. *Energy Nexus.* 2022, Vol. 100030.
2. Thomas B. Johansson, Anand Prabhakar Patwardhan, Nebojša Nakićenović, Luis Gomez-Echeverri. *Global Energy Assessment.* Cambridge University Press : s.n., 2012.
3. *Role of renewable energy sources in environmental protection: A review.* N.L, Panwar. S,C,Kaushik,Surendra Kothari. 2011, Renewable and Sustainable Energy Reviews, págs. 1513-1524.
4. Shahzad, U. The need for renewable energy sources. *ITEE Journal.* 2012, págs. 16-18.
5. Norman, R.S. Water salination-source of energy. *Science.* 1974, Vol. 4161, págs. 350-352.
6. Jan W. Post, Joost Veerman, Hubertus V.M. Hamelers,Gerrit J.W. Euverink, Sybrand J. Metz. Kitty Nymeijer, Cees J.N Buisman. alinity-gradient power: Evaluation of pressure-retarded osmosis and reverse electrodialysis. *Journal of Membrane Science.* 288, 2007, 2007, págs. 218-230.

7. Peng-Fei Sun, Taek-Seung Kim,Han-Shin Kim,So-Young Ham,Yongsun Jang,Yong-Gyun Park,Chuyang Y. Tang,Hee-Deung Park. Improved anti-biofouling performance of pressure retarded osmosis (PRO) by dosing with chlorhexidine gluconate. *Desalination.* 2020, Vol. 481, 114376.

Session B6: Circular design for increased resilience II

How circular design and integrated planning approaches may increase resiliency and biodiversity: a case study based on the construction and maintenance of road infrastructure in Germany and Israel.

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ABSTRACT

Circular design and integrated planning approaches offer significant benefits for both biodiversity and road infrastructure, making them particularly relevant for engineers. These approaches can help engineers in their role of designing and managing roads infrastructure to integrate environmental considerations and enhance resilience.

Circular design principles provide engineers with strategies to minimize resource consumption, waste generation, and environmental impact in road construction and maintenance. Engineers can incorporate recycled and renewable materials, employ sustainable construction techniques, and promote circular economy practices. By doing so, they contribute to the preservation and enhancement of biodiversity, as well as reduce the ecological footprint of road infrastructure.

Integrated planning approaches allow engineers to consider the broader ecological context in which roads exist. Engineers can collaborate with environmental experts and stakeholders to conduct thorough environmental assessments, identify sensitive habitats, and design road networks that minimize fragmentation and disturbance. Integrated planning enables the incorporation of wildlife crossings, green corridors, and other nature-based solutions that facilitate the movement of wildlife and support biodiversity conservation.

Engineers can also leverage integrated planning to identify opportunities for habitat restoration and conservation projects within and around road infrastructure. By integrating green infrastructure elements and wildlife-friendly landscaping, engineers can create ecological corridors and contribute to biodiversity enhancement.

By embracing circular design and integrated planning approaches, engineers can play a crucial role in creating resilient roads infrastructure that mitigates environmental impacts, preserves biodiversity, and fosters sustainable development. These approaches empower engineers to contribute to the broader goal of achieving infrastructure systems that are not only functional and durable but also ecologically sensitive and resilient.

In particular, investigated in this paper is the question: How circular design principles provide engineers with strategies to minimize resource consumption, waste generation, and environmental impact in road construction and maintenance?

Circular design principles provide engineers with a range of strategies to minimize resource consumption, waste generation, and environmental impact in road construction and maintenance. These strategies include:

Material Selection: Engineers can prioritize the use of recycled and renewable materials in road construction, reducing the need for extracting virgin resources. Utilizing recycled asphalt, concrete, and aggregates, as well as incorporating renewable materials like bio-based binders, helps minimize resource consumption and waste generation.

Resource Efficiency: Circular design encourages engineers to optimize material use during road construction. This involves accurately estimating material quantities, reducing overdesign, and employing efficient construction techniques to minimize material waste. By maximizing resource efficiency, engineers can reduce the environmental impact of road construction and decrease the demand for raw materials.

Life Cycle Thinking: Engineers can adopt a life cycle perspective when designing roads, considering the environmental impacts throughout the entire lifespan of the infrastructure. This involves analyzing the energy and resource inputs, as well as the potential environmental emissions associated with road construction, maintenance, and eventual end-of-life scenarios. By considering the full life cycle, engineers can identify opportunities to reduce environmental impacts and make informed decisions about design choices.

Closed-Loop Systems: Circular design principles promote the concept of closed-loop systems, where materials from road construction and maintenance are recycled and reused. Engineers can explore innovative technologies and processes for recycling asphalt, concrete, and other road materials, ensuring that these materials are diverted from landfill and reintroduced into new road projects. Implementing closed-loop systems reduces waste generation and preserves valuable resources.

Circular Economy Strategies: Engineers can embrace circular economy strategies such as product longevity, repairability, and modularity. Designing roads for longevity and easy maintenance allows for extended service life and reduces the need for frequent reconstruction. Emphasizing repairability and modularity enables damaged road sections to be repaired or replaced without significant waste generation or disruption to the entire infrastructure.

By incorporating these circular design principles into the construction and maintenance in road infrastructure practices, engineers can significantly minimize resource consumption, waste generation, and environmental impact. These strategies promote sustainable resource management, reduce the carbon footprint of roads, and contribute to the overall goal of achieving a more circular and sustainable infrastructure system.

By incorporating recycled and renewable materials, optimizing resource efficiency, and adopting a life cycle perspective, engineers can reduce the ecological footprint of roads. This aligns with the goals of biodiversity preservation and sustainability.

Integrated planning approaches, as emphasized in the sustainability strategy of two different companies from Germany and from Israel may enable engineers to consider the broader ecological context in road infrastructure development. By collaborating with environmental experts and stakeholders, conducting thorough environmental assessments, and incorporating nature-based solutions and other positive nature impact solutions, engineers can design road networks that minimize fragmentation and disturbance, while promoting habitat connectivity and biodiversity conservation.

The research of the German and Israeli companies of construction and maintenance of road infrastructure offered in this paper may be instructive. The research findings offer a critical case study of both (A) an overview of a set of challenges in the process of implementing circular design and integrated planning approaches to enhance the resiliency of biodiversity in the sector of road infrastructure side by side with (B) actions that have been applied and can be considered best practices in this process of implementation. This research may serve as an example as well as a valuable reference for engineers, providing realistic and practical insights and inspiring them to integrate these approaches into their own projects.

Regenerative economics for assessing and monitoring transitions towards a circular economy

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Keywords: resource-use efficiency, resilience, robustness, sustainable development, degrowth

ABSTRACT

Besides eliminating waste and pollution and circulating materials and products for as long as possible, the third key principle of a circular economy which is about regenerating nature, is often left unaddressed [1]. Here, we argue that regeneration needs to become central in the transition to a circular economy, and, as an emerging scientific field, *regenerative economics* can fill this gap by offering an eco-mimicry approach with principles, methods, and comprehensive indicators [2, 3]. We summarize the findings from three research papers to demonstrate the application of a dashboard of indicators from ecological network analysis and ascendency analysis for assessing and monitoring the regenerative potential of socio-economic systems at different levels of granularity (Figure 1).

In our first study, we analysed the socio-economic metabolism (SEM) of all EU27 Member States in terms of their *robustness* [4]. In other words, we examined if their balance between resource use efficiency and resilience in their SEMs resembles the balance that has been observed for healthy natural ecosystems [3]. We did so by assessing Eurostat's reported values on the material flows and on the *circular material use rate* (CMR) for each one of the EU27 Member States between 2010 and 2018 expecting that an increased circularity would intuitively correspond to an increase both in resource-use efficiency and resilience, and hence robustness. We chose to study the CMR since it is one of the indicators from Eurostat's monitoring framework which is frequently used to report progress towards a circular economy as a fraction of recycled materials re-entering the European economy:

$$\mathrm{CMR} = \frac{\mathrm{RCV_R\text{-}IMP_W + EXP_W}}{\mathrm{DMC + RCV_R\text{-}IMP_W + EXP_W}}$$

where $\mathrm{RCV_R}$ is the amount of materials that are recovered by *"any operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes, and includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations"* [5], $\mathrm{IMP_W}$ and $\mathrm{EXP_W}$ are the imported and exported waste for recycling purposes, respectively, and DMC is the domestic material consumption calculated as:

$$\mathrm{DMC = DE + IMP_t\text{-}EXP_t}$$

where DE is the domestic extraction of natural resources, and $\mathrm{IMP_t}$ and $\mathrm{EXP_t}$ are the total imports and total material exports, respectively. All terms are typically measured in Gt/year.

For the years studied, we found an overall increase in the CMR values for most Member States which corresponded to a general increase in *robustness* values but only up to a point [4]. Surprisingly, for the Netherlands which was leading in terms of CMR performance for more than a decade (with 25% in 2010 to nearly 34% in 2021), increasing CMR values corresponded to decreasing *robustness* values [4]. In the context of the adaptive cycle which describes ecological succession, a low *robustness* value due to a high *degree of order* (i.e., high efficiency in streamlining resources through its system due to a rather linear network structure) indicates a natural ecosystem which is potentially brittle and susceptible to shocks [3].

Then, the conjecture is that a low *robustness* value due to a high CMR could be a relevant indicator of fragility also for socio-economic systems, particularly when they have a linear socio-metabolic structure.

This led us to engage in a follow-up study together with researchers who are experts on circular economy, strong sustainability, and network-based methods. We conducted a parametric analysis to explore the influence of $\mathrm{RCV_R}$ and $\mathrm{EXP_t}$ on the CMR and on other network-based indicators, and we considered the theoretical case of the EU27 (as a whole) transitioning successfully to a circular economy within its given and largely linear socio-metabolic structure [6]. The assumptions made were that the EU27 manages to: 1) not grow further in terms of material flows, 2) reduce substantially its material imports by becoming more self-sufficient, 3) close its waste material flows within its borders, and 4) redirect effectively waste streams from backfilling towards other useful purposes. This modelling exercise highlighted three aspects. Firstly, 100% CMR, as measured by Eurostat, seems unlikely to occur because it would imply a European economy which either exports everything or which recycles everything, or which follows any proportional combination of the two with the constraint that the domestic material consumption is zero [6]. Secondly, the linear network structure of the material flow metabolism of the EU27 showed a theoretical limit to its *robustness* [6]. Interestingly, the maximum *robustness* value achieved for the years studied did not correspond to 100% CMR (as one who is unfamiliar with concepts and indicators used in ascendency analysis would intuitively expect) but to a much lower value between 30%-40% [6]. Thirdly, this maximum *robustness* was considerably lower [6] than what has been observed for healthy natural ecosystems [3].

In the third paper, we zoomed in Samothraki, a Greek island in the north Aegean [7,8], to examine its SEM by using published time series data between 1929 and 2019 [9] which have been derived from socio-metabolic research [10]. To conduct this study, we extended our collaboration with researchers from the initiative *Metabolism of Islands* [11] and from the association *Sustainable Samothraki* [12] who have studied this island extensively [9], with experts on circular economy, and with researchers from the *Research Alliance from Regenerative Economics* (RARE) [13] who have developed the incumbent framework of regenerative economics [2]. The results showed that indicators from regenerative economics are useful not only for examining *ex post* the evolution of the regenerative potential of an island's SEM by analysing historical data on material flows but also for assessing *ex ante* the implications of different theoretical future scenarios which relate to the implementation of circular economy measures and policies [8]. The study also underlined that by using network-based indicators it is possible to demarcate quantitatively a SEM's biophysical growth (in terms of *total system throughput* expressed as the size of all material flows in a year) from its qualitative network development (in terms of network properties which include its *resilience* and *capacity to develop*, among others) [8]. It also became clear that a single indicator is not sufficient for providing a full picture of the regenerative potential [8]. Finally, this case study also showed that the results of such network-based tools always need to be triangulated with historical knowledge of the local context stressing the need for engaging in transdisciplinary research [8]. These are important considerations for decision makers as they highlight the benefits of collaboration and of adopting a multi-indicator approach for capturing a system's progress towards a regenerative and inclusive circular economy.

The theoretical underpinning of *regenerative economics* is based on energy network science and information theory [2]. It offers rigorous diagnostic tools and ample room for further exploration for theoretical innovation and practical applications not only at the macro- level as we have shown here, but also at the meso- and micro-levels (e.g., business ecosystems, individual organizations, SMEs, etc.) [2]. Due to the holistic nature of its framework, not all its principles can be captured quantitatively [2]. Consequently, qualitative methods also need to be integrated to effectively address principles such as the collective learning ability of local societies. Most importantly, *regenerative economics* provides a hopeful and constructive vision for an inclusive and prosperous *circular society* which follows ecological principles to address social needs and well-being while respecting planetary boundaries. The ambition (and challenge) is to do so while restoring and regenerating the currently declining bio-productive capacity of natural ecosystems [14] to avoid the realistic threat *"where further development without environmental damage is no-longer possible* […] *and where the shrinking resource base urges for a so-called sustainable retreat"* [15].

Figure 1. Application of quantitative network-based tools from regenerative economics at an EU level [4;6] and at an island level [8].

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References:

[1] Ellen MacArthur Foundation. (2019). The circular economy in detail. www.ellenmacarthurfoundation.org

[2] Fath, B. D., Fiscus, D. A., Goerner, S. J., Berea, A., & Ulanowicz, R. E. (2019). Measuring regenerative economics: 10 principles and measures undergirding systemic economic health. *Global Transitions*, 1, 15–27.

[3] Ulanowicz, R. E., Goerner, S. J., Lietaer, B., & Gomez, R. (2009). Quantifying sustainability: Resilience, efficiency and the return of information theory. *Ecological Complexity*, 6(1), 27–36.

[4] Zisopoulos, F. K., Schraven, D. F. J., & de Jong, M. (2022). How robust is the circular economy in Europe? An ascendency analysis with Eurostat data between 2010 and 2018. *Resources, Conservation & Recycling*, 178(106032).

[5] Eurostat. (2021). Circular material use rate. https://ec.europa.eu/eurostat/web/products-datasets/-/cei_srm030

[6] Zisopoulos, F. K., Teigiserova, D., Schraven, D., de Jong, M., Tong, X., & Ulanowlcz, R. E. (2022). Are there limits to robustness? Exploring tools from regenerative economics for a balanced transition towards a circular EU27. *Cleaner Production Letters*, 3(100014).

[7] Zisopoulos, F. K., Noll, D., Singh, S. J., Schraven, D., de Jong, M., Fath, B. D., Goerner, S., Fiscus, D., & Ulanowicz, R. E. (2022). Regenerative economics at the service of islands: Assessing the socio-economic metabolism of Samothraki in Greece, *3rd Symposium on Circular Economy & Sustainability*, Chania, Crete, Greece.

[8] Zisopoulos, F. K., Noll, D., Singh, S. J., Schraven, D., de Jong, M., Fath, B. D., Goerner, S., Webster, K., Fiscus, D., & Ulanowicz, R. E. (Accepted). Regenerative economics at the service of islands: Assessing the socio-economic metabolism of Samothraki in Greece. *Journal of Cleaner Production*, xx(xx).

[9] Noll, D., Lauk, C., Haas, W., Singh, S. J., Petridis, P., & Wiedenhofer, D. (2022). The sociometabolic transition of a small Greek island: Assessing stock dynamics, resource flows, and material circularity from 1929 to 2019. *Journal of Industrial Ecology*, 26(2), 577–591.

[10] Haberl, H., Wiedenhofer, D., Pauliuk, S., Krausmann, F., Müller, D. B., & Fischer-Kowalski, M. (2019). Contributions of sociometabolic research to sustainability science. *Nature Sustainability*, 2(3), 173–184.

[11] Metabolism of Islands. https://metabolismofislands.org/ Accessed: 10 March 2023

[12] Sustainable Samothraki. http://sustainable-samothraki.net/ Accessed: 10 March 2023

[13] Research Alliance for Regenerative Economics (RARE). https://rare-sci.net/ Accessed: 10 March 2023

[14] Keller, A. (2019). Collapse: The only realistic scenario? NEXT. https://www.youtube.com/watch?v=qPb_0JZ6-Rc

[15] Muys, B. (2013). Sustainable development within planetary boundaries: A functional revision of the definition based on the thermodynamics of complex social-ecological systems. *Challenges in Sustainability*, 1(1).

Voluntary standards, as a way how the food industry and retailers control impact of their supply chains on ecosystem services provided by soil

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Keywords: retail, food, soil

ABSTRACT

Substantial majority of food used by humanity depends on soil. Human population as well as per capita consumption are growing, this growth requires development of agriculture. At the same time, increasing proportion of human population lives in cities which causes detachment of consumers from soil and food production. Agricultural intensification has increased crop production but at the same time may bring negative environmental effects. Food market chains are, with a few exceptions, driven by retailers who determine sales strategies, price structure, production standards etc. Price is one of the key factors determining customer decisions. Pressure for lower prices can contribute, together with decreasing labor force in agriculture and many other factors, to increased pressure on farm intensification which have negative feedback to environment, society but also to stability of food market supply chain as explained above. However, an increasing number of food retailers and food and beverage companies view environmental impacts of intensification, including soil degradation, as a risk to stability of their supply chains. They seek options to ensure more sustainable food production. Businesses employ standards and other interventions to steer their suppliers towards preferred practices either as part of their direct contact with suppliers or by using various certification and monitoring schemes operated by third party. This concept is now well established in biodiversity and prevention of deforestation. Nevertheless, soil protection has been emerging as a priority topic as well. Business engagement in soil protection will require effective instruments that can be applied in supply chains. Here we summarize our experiences with development soil protection guidelines in cooperation with Czech Confederation of Commerce and Tourism.

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Measurement scale validation for inner and outer circular economy loops: a proposal based on food and beverage circular packaging and wishcycling.

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Keywords: circular packaging; consumer behaviour; measurement scale construction; measurement scale validation

ABSTRACT

For the last 70 years, food and beverage packaging has become indistinguishable with the goods they preserve. In reality, when consumers purchase a food product from supermarkets, they are buying a by-product as well, which is mainly considered from the start as waste. Although food and beverage packaging are essential for the protection and preservation of goods (Robertson, 2005) and extensive research has been made towards those attributes, the solutions are mainly based on a linear economy concept (Sæter et al., 2020).

Single-use plastic is the preliminary source of packaging with the European Union producing 23 million tons of plastic packaging and a forecast of 92 million tons by the year 2050 (Guillard et al., 2018). Sustainable development in a linear system consists of material recycling (Borrello et al., 2020), and although large-scale recycling has been introduced for more than 40 years, only 14% of plastic is recycled globally (WEF, 2016) and 80% of plastic ends up in landfills or the environment (Brooks et al., 2018). According to Geyer et al. (2017), recycling delays, and does not avoid, the end-of-life disposal of materials, highlighting the issue that recycling should not be the primary option when trying to tackle the food and beverage packaging problem (Chakori, 2021).

Although recycling is the first thing that people envision when they hear the term “Circular Economy”, such practices are placed at the bottom of the circular hierarchy, and in some cases, recyclability can be worse than using virgin materials (Sarkis et al., 2022). Circular economy, as a restorative and regenerative by-design paradigm (Baran, 2019), is offering valuable solutions for creating slow, narrow, intense, and closed resource loops (Geissdoerfer, 2018). Therefore, packaging which is created using the principles of the circular economy needs to protect natural resources, maximise their usage, and reduce their detrimental effects on the environment (EMF, 2012). The main principle of circular packaging is the idea of “designing out waste” which summarises the concept (Szaky, 2019).

The way recycling has been performed in the last years has led to consumer confusion and the act of “wishcycling”. Wishcycling, also known as aspirational recycling (Winterich et al., 2023), is the practice of disposing of questionable items in recycling bins, in the hope they will get recycled somewhere down the line (Somerville, 2017). The term is a play on the word "wishful" since people wish that certain items were recycled, although they are not. According to Brundell (2022), there are three significant reasons why it causes problems for councils and recycling companies: wishcycling contaminates and leads to waste, it decreases the quality of the raw material, and it damages the machinery.

To advance in behaviour change, CE adoption and policy-making towards circular economy, we need to create appropriate metrics (Linder et al., 2020) and advance on the theoretical and empirical frameworks which will allow the design and validation of the measurement models (Asokan, Yarime, & Onuki, 2019).

In this study, we introduce trustworthy and reliable scales for accessing wishcycling consumer practices to broaden the understanding of circular packaging adoption in the domain of food and beverage. To achieve this, we adopt the definition of inner and outer loops by Barford and Ahmad (2023) which in turn is based

on EMF's butterfly diagram (2012) and UNEP's formulation of circular economy (2019). The diagram in Figure 1.1. presents the inner loops as the most circular practices (inner closed loops) and the outer loops as the least desirable of material loops (recycling being the most outer loop). Measuring the outer loops will provide an indicator to policymakers and relevant stakeholders of the importance of investing in the inner loops of the circular economy, as we assume that causal relationships between the loops exist. To be able to observe this phenomenon, measurement scales would need to be established.

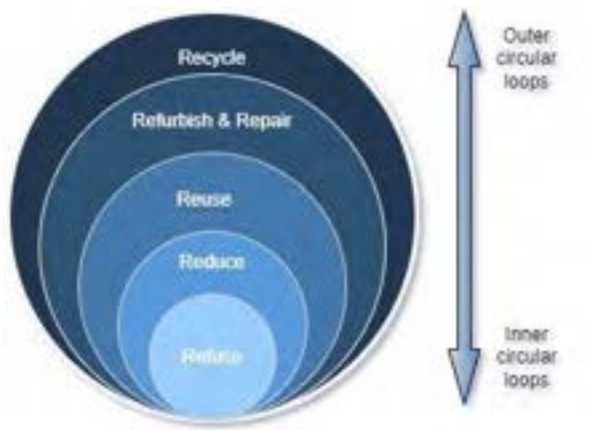

Figure 1.1. Inner and outer loops in circular economy. Adapted from: Barford and Ahmad (2023)

In this paper, we aim to explore the above by creating measurement scales by studying well established literature in the fields of food and beverage circular packaging and consumer wishcycling.

To create measurement scales for the food and beverage circular packaging we follow the approach introduced by Testa, Iovino and Iraldo (2020) who have researched the packaging as a communication vehicle between the consumer and the companies, and we adapt it to the food and beverage packaging context.

For the consumer wishcycling measurement scale, we adapt the approach of Oehman, Babbitt and Flynn (2022) who have created a structural equation model on the separation of food waste grounded on the theory of planned behaviour. By introducing the wishcycling literature into their findings we aim to create a measurement model for wishcycling.

Using the above-mentioned measurement scales, a survey was developed which has been administered by Prolific[7]. To test the measurements, an exploratory factor analysis (EFA) was conducted, and the results show that the measurements are acceptable for further use. Findings show that there are differences between general circular packaging practices and food and beverage specific practices, suggesting that the measurements will need to be granular and problem domain based. We also identify a causality between circular food / beverage packaging and consumer wishcycling.

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References:

Asokan, V. A., Yarime, M., & Onuki, M., 2019. A review of data-intensive approaches for sustainability: methodology, epistemology, normativity, and ontology. Sustainability Science, https://doi.org/10.1007/s11625-019-00759-9

[7] http://www.prolific.co

Baran, B.,2019. The circular economy in eu policy as a response to contemporary ecological challenges. Gospodarka Narodowa. The Polish Journal of Economics, 300(4), 31-51, https://doi.org/10.33119/GN/113064

Barford, A. and Ahmad, S.R., 2023. Levers for a corporate transition to a plastics circular economy. Business Strategy and the Environment, 32(4), pp.1203-1217, https://doi.org/10.1002/bse.3182

Borrello, M., Pascucci, S., & Cembalo, L., 2020. Three propositions to unify circular economy research: A review. Sustainability, 12(10), 4069, https://doi.org/10.1016/j.jclepro.2006.08.003

Brooks, A. L., Wang, S., & Jambeck, J. R.,2018. The Chinese import ban and its impact on global plastic waste trade. Science advances, 4(6), eaat0131, http://doi.org/10.1126/sciadv.aat0131

Brundell, N.,2022. What is Wishcycling? TheDos and Don'ts of Recycling, https://lochtree.com/blogs/blog/what-is-wishcycling

Chakori, S., Aziz, A. A., Smith, C., & Dargusch, P., 2021. Untangling the underlying drivers of the use of single-use food packaging. Ecological Economics, 185, 107063, https://doi.org/10.1016/j.ecolecon.2021.107063

EMF., 2012. Towards the circular economy: Economic and business rationale for an accelerated transition. https://www.ellenmacarthur foundation.org/assets/downloads/publications/Ellen-MacArthur-Foun dation-Towards-the-Circular-Economy-vol.1.pdf

Geyer, R., Jambeck, J. R., & Law, K. L., 2017. Production, use, and fate of all plastics ever made. Science Advances, 3(7), e1700782, http://doi.org/10.1126/sciadv.170078

Geissdoerfer, M., Morioka, S. N., de Carvalho, M. M., & Evans, S., 2018. Business models and supply chains for the circular economy. Journal of cleaner production, 190, 712-721, https://doi.org/10.1016/j.jclepro.2018.04.159

Guillard, V., Gaucel, S., Fornaciari, C., Buche, P., & Gontard, N., 2018. The Next Generation of Sustainable Food Packaging to Preserve Our Environment in a Circular Economy Context. Frontiers in Nutrition, 5, https://doi.org/10.3389/fnut.2018.00121

Kramer, E., Yoeli, E. and Rand, D., 2023. Counterproductive norms can be addressed via informational interventions: The Case of 'Aspirational Recycling'.

Linder, M., Boyer, R. H. W., Dahllöf, L., Vanacore, E., & Hunka, A., 2020. Product-level inherent circularity and its relationship to environmental impact. Journal of Cleaner Production, 121096, https://doi.org/10.1016/j.jclepro.2020.121096

Oehman, J.M., Babbitt, C.W. and Flynn, C., 2022. What predicts and prevents source separation of household food waste? An application of the theory of planned behavior. Resources, Conservation and Recycling, 186, p.106492, https://doi.org/10.1016/j.resconrec.2022.106492

Sæter, F., Alvarado, I. O., & Pettersen, I. N., 2020. Reuse principle for primary packaging circularity in the food system. DS 101: Proceedings of NordDesign 2020, Lyngby, Denmark, 12th-14th August 2020, 1-12, https://doi.org/10.35199/NORDDESIGN2020.3

Sarkis, J., Dewick, P., Cohen, M. J., Hofstetter, J. S., & Schröder, P., 2022. Coordinating Circular & Degrowth Systems for Strong Sustainability. by Andrew J. Hoffman and Nicholas Poggioli, Guest Editors, 12.

Somerville, M. S. M., 2017. 3 Big Reasons "Wish-cycling" Is Always a Bad Idea, https://earth911.com/living-well-being/wish-cycling/

Szaky, T. (2019). The future of packaging: from linear to circular. Berrett-Koehler Publishers

Testa, F., Iovino, R. and Iraldo, F., 2020. The circular economy and consumer behaviour: The mediating role of information seeking in buying circular packaging. Business Strategy and the Environment, 29(8), pp.3435-3448, https://doi.org/10.1002/bse.2587

UNEP. (2019). Understanding circularity. UNEP Circularity Platform. https://buildingcircularity.org/

WEF., 2016. The New Plastics Economy: Rethinking the future of plastics. World Economic Forum Report. https://www.weforum.org/reports/the-new-plastics-economy-rethinking-the-future-of-plastics

Winterich, K.P., Reczek, R.W. and Bollinger, B., 2023. Reducing Emissions across the Consumption Cycle and an Agenda for Future Research on Consumers and Climate Change: Introduction to the Special Issue on Climate Change. Journal of the Association for Consumer Research, 8(3).

It is a waste to waste waste: examples of circularity in Kenya and Mali

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Keywords milk, dairy, circularity, Kenya, cotton oil, Mali

ABSTRACT

"Over the years in the field of dairy preparation a radical change took place. Where people processed the milk on the dairy, people more and more do this cooperative or sell the milk to third parties for same goal. The causes that lead to this can be done here remain unspoken, but the result is that the dairy preparation gradually moved to the dairies and these increase annually in number. This not only has advantages but also disadvantages. One of the drawbacks which the factory dairy production is connected, is the removal waste water without causing problems for the surroundings. Formerly when the company exercised exclusively was on the scattered farms, this was of subordinate importance; the amount of scrub and scrubbing water was usually not so big that it could be discharged in ditch or canal, without, nuisance to the neighbours. The dairies were not a change for the better. Where thousands of litres of milk are processes at a central point, it is obvious the large quantities of resulting waste water, poured into a relatively small surface, cause nuisance in the immediate vicinity. Which wastewater still contains a lot of nitrogen-containing organic matter soluble and suspended condition, substances that cause various odor-spreading degradation products. In the beginning few complaints were heard; as however, the number of dairies increased and especially when these more in the built-up area of the municipalities, people started to become aware of the untenable condition that was thereby created. It therefore needs not to be surprised, that in the Health Committee, seated in Hoorn, complaints were brought in about two dairies located in the built-up area of one of the municipalities ……"

From: 'De biologische reiniging van het afvalwater van zuivelfabrieken (Biological treatment of waste water from diaries), Boekhout and Ott de Vries, J.J., published in 1915 by Rijkslandbouwproefstation in Hoorn.

To summarise: in the world of my grandfather it was a world without wastes. It was a pinnacle of a circular waste, there was just no money to waste…

This lesson was for me the starting point when I was confronted with the question: 'please help us with a biobased solution for our dairy?' My reply: 'how can milk be a waste? What are you doing wrong?'. It lead to a solution for of not wasting milk, turning not used milk to pig food, separation of flows, and a garden for use of the thin "not wasted wastes for the Ndumberi Dairy Farmers Cooperative Society.

The same approach has been used in a cotton oil factory in Koutiala in Mali.

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References:

www.researchgate.net/publication/341931979_White2Green_No_discharge_dairy_through_recovery_of_milk_and_food-chain_approach_-_Ndumberi-_part_1_-_Inventarisation_and_ideas_and_over_one_year_experience

www.researchgate.net/publication/330143979_Koutiala_towards_a_Circular_City_Solving_sanitation_waste_and_waste_water_problems_with_an_urban_circular_approach_A_cooperation_between_the_cotton_industry_and_the_community_of_Koutiala_Mali_Koutiala

Training a new generation of farmers and agricultural entrepreneurs to implement the concept of circular economy in agriculture – the TANGO-Circular Erasmus plus project.

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Keywords:
Agriculture, animal husbandry, waste, circular economy, farmers, training.

ABSTRACT

The volume of wastes produced by agricultural and livestock activities is constantly rising. This is a result of the continuous increase of crop and livestock production, in order to cover the nutritional needs of the accreting population of the planet. This enormous mass of wastes, coming straight from agriculture and animal husbandry as well, has a significant environmental impact. A very promising way to reduce the impact of agriculture on the environment, passes through the valorization of crop residues, agricultural by-products and other materials such as plastics used for crop cultivation and animal production currently considered as wastes. Hence, for a sustainable agriculture and under the perspective of circular economy, it is necessary to address the issue of properly managing such agricultural residues and by-products as also other materials considered as "waste". By upgrading and spreading the valorization methods of agricultural residues, by-products and plastics, many advantages can be recognized. More specifically, the utilization of agricultural materials can contribute to strengthening the economic inputs of producers, ensuring a sustainable way of collecting, transporting and managing unused materials for the production of energy or new goods. Education of farmers on such issues of circular economy is imperative for environment protection and economy enhancement.

Aim of this work is the contribution to the development of regional ecosystems directly providing a valuable input to the economy, by integrating work-based learning thanks to a Quadruple-Helix approach involving Public Institutions (Regional/Local Ministries/Agencies), RTD performers/ VET providers, Private stakeholders (Farmers Associations, Collectors/Recycling Firms/Associations, etc.) and the Civil Society (NGO, No-profit Association, etc.). A useful tool that will contribute to the education of the potential learners will be the modelling, implementation and validation of the Project "Rural Labs" in which, under the coordination of some of the most important Universities of Mediterranean Europe, experts in agricultural waste management, farmers and other relevant stakeholders will be trained. New ways of training will be explored, starting from an on-site training, and implementing new ICT tools, to be produced for the sake of a larger audience of trained people, working in the Project Countries as well as in the rest of Europe.

Trainees in the field of agriculture and youth farmers, as well as relevant stakeholders and enterprises involved in the specific sector's activities, will benefit from the short, medium and long-term effects of the Project. It is important to refer to the impact of the project in the labour market and the long-term effects. Specifically, enterprises and stakeholders in the field would have the opportunity to upgrade their efforts to minimize the agricultural waste.

Some of the expected short, medium and long-term effects of this work, depending of the different actors, will be:

Academia, referring not only to participating HEIs

- Strengthen its links with the agricultural business communities and stakeholders for bilateral feedback and long-term benefits;
- Enrich their training curricula portfolio with updated material related to agricultural waste valorization, in accordance to the Education and Training 2020 strategy which pursues green skills and sustainability, and sustainable growth (2018-2020 mandate);
- Provide the opportunity for the establishment of new specialization training programmes targeted to this project's intended beneficiaries and thus ensuring its lasting effect.

Agricultural sector

- Young farmers will obtain innovative and interactive training on the valorization of agricultural waste, as well as on relevant best practice examples. This training will result in innovative changes and increased productivity and competitiveness in their operations.

Local, regional, national, European and/or international level

- The expected geographical impact refers to significantly enhance the competitiveness of the farming communities in the different regions and create the necessary infrastructure for the continuous adoption of beneficial training as well as through the successful dissemination of such VET format in neighbouring regions. Nationally, it is expected to empower in the long-term, young farmers particularly, with the knowledge, skills, and key competences for tackling the environmental and economic challenges associated with food production and agriculture, energy consumption, cost-effectiveness and waste reduction. The benefits of remote communities nationally arise from the improved protection of the environment and efficiently use of resources, particularly the exploitation of solid waste. This support long-term the remote communities to tackle the adverse impacts from multiple economic, environmental and social challenges

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Towards Sustainable Food systems deploying Circularity Compass Strategy

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Keywords: Circular Economy, Circularity Thinking, Food

ABSTRACT

Circular economy is an economic model and concept that aims to design and promote sustainable systems by reducing waste, maximizing resource efficiency, and reusing or recycling materials to minimize environmental impact.

In the context of the circular economy course “Creating Circular Strategies for the Food Sector” from EIT Climate-KIC, (2022) a circularity compass was developed for the flow of vegetables. This compass visualizes the entire journey of vegetables, starting from their transportation in trucks to supermarkets, and ultimately being consumed by customers. To tackle the issue of significant vegetable waste at specific points in the process, three solutions were identified and thoroughly analyzed for their practical implementation:

- The first solution involves addressing vegetables that either expire or get damaged during transportation. The proposal is to convert these vegetables into biofuel, which can then be used to power specially designed trucks responsible for transporting the vegetables. This circular approach not only reduces waste but also promotes the use of renewable energy sources in the transportation sector.
- The second solution centers around the use of the "TooGoodToGo" app. Through this application, consumers can directly connect with supermarkets and purchase vegetables that are nearing expiration at discounted prices. By availing these products, consumers contribute to reducing food waste while accessing affordable and fresh products.
- The third and final solution involves the distribution of vegetables that are about to expire to charities. By redirecting these perishable items to charitable organizations, they can be utilized to support those in need and minimize unnecessary waste.

The last solution is implementing for one month in one shop of the supermarket chain “Pitsias” and the results are expected.

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References:

Nikolaou, I.E., Jones, N., Stefanakis, A.I., 2021. Circular Economy and Sustainability: the Past, the Present and the Future Directions. Circular Economy and Sustainability 1, 1-20, https://doi.org/10.1007/s43615-021-00030-3

Stefanakis, A.I., 2018. Constructed Wetlands for industrial wastewater treatment, first ed. John Wiley & Sons Ltd, Chichester, UK.

Stefanakis, A.I., 2020. Constructed Wetlands for Sustainable Wastewater Treatment in Hot and Arid Climates: Opportunities, Challenges and Case Studies in the Middle East. Water 12 (6), 1665, https://doi.org/10.3390/w12061665.

Matti, Jensen, Bontoux, Goran, Pistocchi, Salvi, Towards a fair and sustainable Europe 2050:
social and economic choices in sustainability transitions, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/804844, JRC133716

Krijgsman, A., Beers, PJ., Fraaije, M., Hebinck, A., Mulders, W., Robison, R. and Silvestri, G., 2022. SHARED GREEN DEAL. Pathways to a more just & sustainable Europe – What came out of the SHARED GREEN DEAL Transition Arena. Cambridge: SHARED GREEN DEAL.

Bianchi, G., Pisiotis, U., Cabrera Giraldez, M. GreenComp – The European sustainability competence framework. Bacigalupo, M., Punie, Y. (editors), EUR 30955 EN, Publications Office of the European Union, Luxembourg, 2022; ISBN 978-92-76-46485-3, doi:10.2760/13286, JRC128040.

Development of a Blockchain Solution for Food Waste Management

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Keywords: Food Waste, Blockchain, Smart Contracts, Tokenization, Decentralized Applications, Smart Cities

ABSTRACT

Food waste is a problem with serious and multidimensional implications (Manika et al., 2022). Environmentally, it contributes to greenhouse gas emissions and depletion of water and land resources (Sun et al., 2018) and economically, it represents a significant loss of resources and money for both enterprises and society as a whole, as it causes almost $1 trillion per year in economic damages (FAO, 2014). Socially, food waste coexists with of hunger and food insecurity, hence exacerbating disparities. Actions against hunger (SDG 2) and the impacts of food waste (SDG 12.3), are both parts of the Sustainable Development Goals, implemented by United Nations. Especially in metropolitan areas, Food Service Establishments (FSEs) contribute significantly to the problem's development, due to a variety of reasons. Overproduction, insufficient inventory management, poor portioning, plate waste, inefficient food preparation procedures, and customer behaviour (Canali et al., 2016; Özbük & Coşkun, 2020) are some examples of these. Viable strategies are needed to reduce the problem's incidence and, in this context, business owners and consumers should cooperate to adopt effective waste reduction programs, which are able to overcome the complexities and ramifications of food waste. To address food waste in urban FSEs, a holistic approach including all stakeholders is required, and the use of effective technology solutions can play a crucial role towards this direction, especially in the context of smart cities. Local governments and municipalities can also be critical in assisting waste reduction efforts, through legislation and regulations (Treutwein & Langen, 2021), by rewarding business owners and citizens with sustainable habits. In this paper, a project is presented that aspires alleviate food waste in FSEs, by offering free or discounted meals to consumers, especially to food insecure citizens.

The research project presented in this paper, namely BLOCKFOODWASTE, lies in the intersection of two scientific areas e.g., food waste management and blockchain technology. The project's final product is a decentralized application (dApp) that operates as a marketplace providing to its users supply of and demand for food surplus from FSEs. The back-end of the application, as implied by its type, runs on a blockchain network. The Ethereum blockchain was chosen by the project partners, due to its public nature and the capabilities it provides to programmers for the development of smart contracts, which play a critical role for the project's scope. FSEs (supply) and consumers (demand) consist the two main user profiles of the application, but the integrated system provides open access to all stakeholders that can benefit from the project's implementation, i.e., municipalities, local governments, NGOs etc. The main function of the solution, is the supply of food meals, that otherwise would be disposed of, by the FSEs in real time and the reservation and pick up of these meals by the consumers. As a result, food waste transforms in safe and nutritious meals for possibly food insecure citizens, with the complete anonymity provided by the blockchain technology.

The keystone of the proposed ecosystem is the project's token (BFW), which is used as a mean of exchange for the purchase of meals by the consumers, directly through the application. A blockchain wallet is incorporated in the dApp, to provide users with a secure and convenient way to manage their tokens. For the creation of BFWs, solidity language is utilized, in order to develop the project's smart contract that controls token supply and distribution. Food surplus offered by FSEs, acts as the underlying asset that is transformed in BFWs, in this tokenization process. Given that the project's smart contract is a node of a public blockchain, the solution is secure and transparent to anyone and it supports widespread adoption and engagement. The project's token tracks food waste reduction and encourages participation and

behavioural change, as it is offered as incentive. Initially, each citizen is given a number of tokens to spend upon registration and afterwards, the smart contract releases more tokens to both parties (supply and demand) for every successfully completed pick up of food surplus. Citizens utilize the tokens as currency to buy meals or other things from participating business units. This encourages users to participate in food waste reduction efforts in a regular basis. On the other hand, every participating establishment receives tokens as a reward for every portion of food saved from waste, in addition to the tokens that are transferred to it directly, by the consumer. FSEs can use their tokens to gain access to valuable data analytics and advertisement by the platform, transfer the tokens directly to food insecure citizens or gain benefits from the application's stakeholders. Municipalities or waste management companies, are able to offer discounts to the business owners through the application in exchange for their collected tokens, in a way to further motivate FSEs in food waste reduction efforts. Blockchain sets its rules and conditions for token transfer, to guarantee that tokens are utilized effectively and their use is aligned with the project's goal. The authors are currently in the phase of assessing the potential value of the token and the overall tokenomics of the BLOCKFOODWASTE application, by assessing market demand along with basic token characteristics such as, supply, distribution, utility and economics.

Food waste mitigation efforts are essential and possible, especially in metropolitan areas that are characterized as "smart cities". FSEs may considerably reduce food waste, promote sustainability, and contribute to a more resilient and equitable food system by implementing comprehensive initiatives that incorporate all stakeholders, like the blockchain-based approach suggested in this research paper. Due to the solution's ability to guarantee the anonymity of the consumers and its tokenization capabilities, the dApp offers significant advantages to its users, in an effort to promote a sustainable behavioural change towards food waste reduction. So, the above-mentioned blockchain characteristics play a crucial part in the integrated system and the project's ecosystem, which is built around the BFW token, can transform into an integrated solution to tackle food waste on every step of the food supply chain.

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References:

Canali, M., Amani, P., Aramyan, L., Gheoldus, M., Moates, G., Östergren, K., ... & Vittuari, M. (2016). Food waste drivers in Europe, from identification to possible interventions. Sustainability, 9(1), 37.

FAO. (2014). Food wastage footprint. Full-cost accounting. Final Report.

Manika, D., Iacovidou, E., Canhoto, A., Pei, E., & Mach, K. (2022). Capabilities, opportunities and motivations that drive food waste disposal practices: A case study of young adults in England. Journal of Cleaner Production, 370, 133449.

Özbük, R. M. Y., & Coşkun, A. (2020). Factors affecting food waste at the downstream entities of the supply chain: A critical review. Journal of Cleaner Production, 244, 118628.

Sun, S. K., Lu, Y. J., Gao, H., Jiang, T. T., Du, X. Y., Shen, T. X., ... & Wang, Y. B. (2018). Impacts of food wastage on water resources and environment in China. Journal of Cleaner Production, 185, 732-739.

Treutwein, R., & Langen, N. (2021). Setting the agenda for food waste prevention–A perspective on local government policymaking. Journal of Cleaner Production, 286, 125337.

Session B7: Stormwater management

Nature-Based Solutions for flooding risk mitigation in an urban area: The case study of Catania (Sicily, Italy)

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Keywords: Nature-Based Solutions, modelling, urban flooding, hazard, rainfall images

ABSTRACT

Introduction
Urban floods, especially flash floods, are one of the main common challenges at global level related to intensified rainfall due to a changing climate and increased surface runoff due to urbanization. Central Mediterranean Regions are particularly affected to extreme rainfall events with ever-greater flow rates and runoff volumes in low-lying coastal urban areas (Abdessamed & Abderrazak, 2019). It is notable that urban flooding causes huge economic losses and serious threats to public safety. Reducing the impacts of adverse consequences by using adaptation and mitigation measures it is necessary to minimize the potential damages for the risk receptors (i.e. human health and life, environment, cultural heritage, economic activity and infrastructure). Traditional responses and interventions, focused on grey infrastructures approaches, are showing their failure to manage storm water in urban environment. A new response towards flood risk reduction is currently passing under the name of Nature-Based Solutions (NBS) that are strategies increasingly popular in the urban storm water management to minimize water quantity and to improve water quality (Vojinovic et al., 2021). A suitable combination of NBS with traditional grey infrastructures should be adopted to retain, decelerate, infiltrate and slowly release rainwater.
The aim of this study is to identify the flood risk areas, through the application of a hydraulic model (HEC-RAS), and to locate NBS (i.e. green roofs, rain gardens, porous pavements, rain barrels and infiltration basins) in a Sicilian hydrological watershed. HEC-RAS model is tested by using images from traffic and phone cameras, due to the lack of hydrological observations in this urban catchments. Finally, the effectiveness of the implemented small and large-scale NBS is evaluated, in terms of flood peak reduction and delay, and runoff volumes reduction, through EPA SWMM model. This research activity is carried out within a cross-border cooperation project GIFLUID (www.gifluid.eu) funded by the INTERREG V-A Italia-Malta 2014-2020 programme.
Material and methods
A small Sicilian watershed, named as Garibaldi-Nesima, is selected for the risk areas assessment, in order to identify the most suitable locations for the NBS implementation, and for flood mitigation effect evaluation of such green solutions. The Garibaldi-Nesima watershed is located in the Metropolitan Area of Catania (Sicily, Italy) and is a sub-basin of the larger Acquicella watershed extending from the territory of Misterbianco municipality and flowing into the Ionic Sea crossing the city of Catania. The watershed is chosen because, in recent decades, it was often subjected to short but intensive storm events, like the entire metropolitan city of Catania, causing the whole traditional drainage system to fail with several damages to the Garibaldi-Nesima hospital and to the numerous commercial activities in the area. The chosen Garibaldi-Nesima watershed, considering the hospital as basin outlet, covers an area of 8.75 km2. Garibaldi-Nesima watershed elevation ranges from 95.6 to 313.3 m above sea level, the mean elevation is 197.6 m above sea level and the mean basin slope is 9.8%. The main and longest water pathway is about 6.8 km. According to the Land Use (Corine Land cover, 2018), most of the Garibaldi-Nesima watershed is covered by urban areas (56.5%), including industrial areas, while the second most represented land use is the agriculture (42.6%); the remaining part of the catchment is covered by areas of natural vegetation (0.9%). Figure 1 shows a summary of the methodology followed in this study to identify hazard and flood

risk areas where NBS should be effectively located and to evaluate their mitigation effects in the Garibaldi-Nesima watershed.

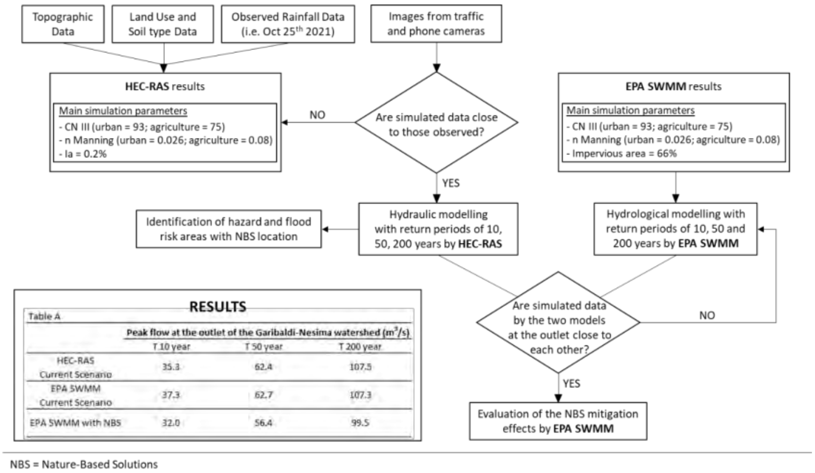

Figure 1 Workflow applied to identify hazard and flood risk areas and to evaluate NBS mitigation effects, and results obtained in the Garibaldi-Nesima watershed.

In particular, the hydraulic model (HEC-RAS) is tested at flood event scale by using images from traffic and phone cameras of an extreme rainfall event occurred in Catania on the 25th October 2021. In figure 2 the rainfall probability curves for return periods (T) of 5, 10, 50 and 200 years of the Catania pluviographic stations (based on the database recorded from 1967 to 2022) and the event occurred in October 2021 are reported. The graph in figure 2 shows that this event ranks near the T of 10 years only for a six hours' duration; for all the other durations it has a higher probability of occurrence (more or less 5 years).

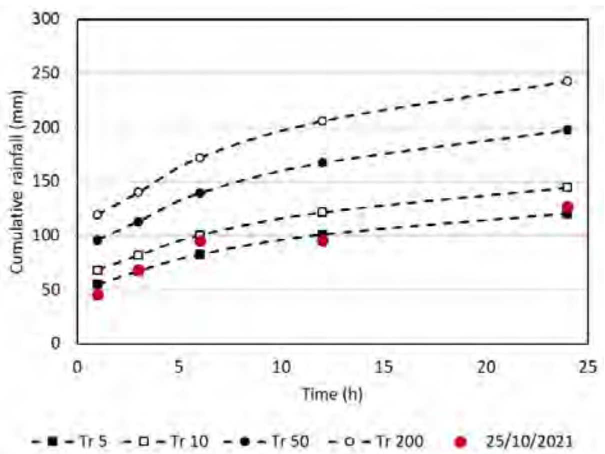

Figure 2 Rainfall probability curves for different return periods of the Catania pluviographic stations with the placement of the event occurred on 25th October 2021 (data by the SIAS, 2021).

After the T assessment for the event considered, the testing phase of the HEC-RAS model reliability is carried out. The observed runoff depths in correspondence of some fixed points (i.e. cars headlights, bumpers and wheels) are compared with those simulated with the hydraulic model for the same T of the rainfall event occurred in October (Figure 3).

Figure 3 Example of how the HEC-RAS model testing phase is carried out. A) Observed runoff depths by using an image of the event occurred in October from Garibaldi-Nesima hospital security camera; B) Google Maps image; C) Simulated runoff depths by using HEC-RAS model; D) Fixed point, back bumper of an Alfa Romeo 147.

After the positive model testing phase, the flood risk areas identified by the hydraulic model (HEC-RAS) are considered for the location of the NBS. Then, the EPA SWMM model was applied in order to obtain peak flows value at the outlet of the watershed similar to those obtained by HEC RAS in the current scenario. Then, the NBS mitigation effects (in terms of peak flow and runoff reductions) into the identified risk areas are evaluated at sub-catchment scale (0.20 km2) through EPA SWMM model. Model simulations are performed with T of 10, 50, 200 years and by considering an area of 0.07 km2 of NBS (in EPA SWMM model) that means 36.8% of the sub-catchment area (Figure 4).

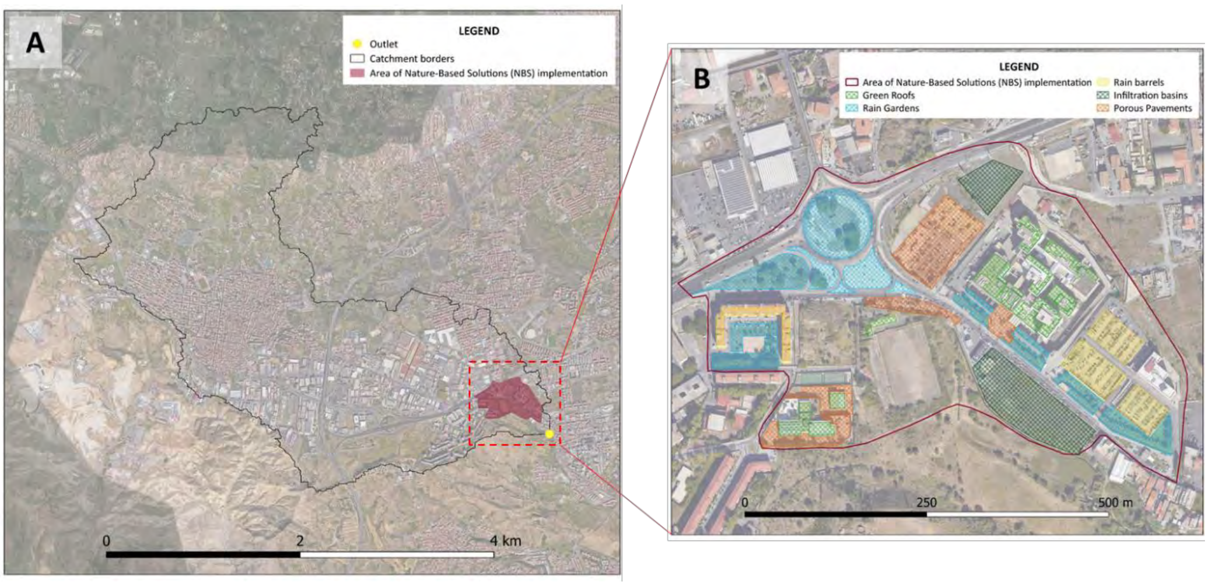

Figure 2 A) Area of Nature-Based Solutions (NBS) implementation within the Garibaldi-Nesima watershed; B) Location of the different NBS typologies within the sub-catchment.

Results and discussion

Preliminary results from the testing process showed satisfactory results. At the four randomly chosen test points, the observed and simulated runoff depth are very close to each other with a difference in the range of 0.01 m - 0.10 m. Table A in figure 1 shows the estimated peak flows (m3/s) obtained from the simulations performed for all the different T in the current scenario using HEC-RAS and EPA SWMM models. In

particular, the estimated peak flow values obtained, at the outlet of the Garibaldi-Nesima catchment, using HEC-RAS and EPA SWMM models are very closed to each other (with a variation of 5.2%, 0.5% and 0.2%, respectively, for T 10, 50, 200 years). In addition, the model EPA SWMM shows its sensibility to NBS implementation at sub-catchment scale with a peak flow reduction up to 14% and a runoff volume reduction up to 9% at the outlet of the Garibaldi-Nesima watershed (Table A in figure 1). NBS mitigation effects are higher for the lower return periods. Figure 5 shows the flood risk map in the Garibaldi-Nesima catchment based on the current scenario with a focus on the area of NBS implementation.

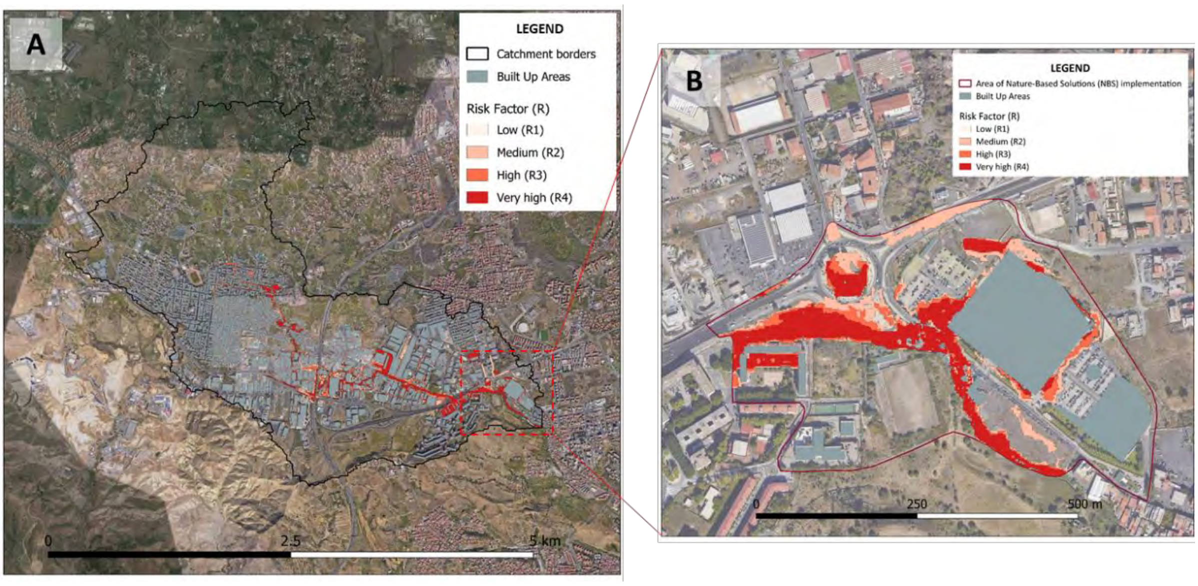

Figure 3 – A) Flood risk map for Garibaldi-Nesima catchment; B) Risk areas in the area of Nature-Based Solutions (NBS) implementation.

Conclusion

The approach proposed in the present study to evaluate NBS mitigation effects in flood risk urban data scarce areas through the application of HEC-RAS and EPA SWMM models, based on images from traffic and phone cameras, is promising. Both the preliminary testing process of HEC-RAS model to simulate observed peak flows in different points in the areas and the comparison of peak flows calculated at the outlet of the Garibaldi-Nesima watershed showed satisfactory results. In addition, the model EPA SWMM is able to simulate the effects in terms of peak flow and runoff volume reduction due to the implementation at sub-catchment scale NBS. The proposed approach is easy to apply and has high replication capacity in urban hydrological scarce areas. Further tests are necessary to test the approach performance by using different datasets also observed in different environments. More in general, the results confirm that the integration of NBS with grey infrastructures in urban area could have hydrological and hydraulic positive effects, in terms of peak flow and runoff volume reduction. Therefore, the proposed approach could be used as a tool to support decision makers, planners and stakeholders to investing in NBS as a green adaptation strategy against climate change in Mediterranean Regions.

Acknowledgements

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References

Abdessamed, D., & Abderrazak, B. (2019). Coupling HEC-RAS and HEC-HMS in rainfall–runoff modeling and evaluating floodplain inundation maps in arid environments: case study of Ain Sefra city, Ksour Mountain. SW of Algeria. *Environmental Earth Sciences*, *78*(19), 1–17. https://doi.org/10.1007/s12665-019-8604-6

Vojinovic, Z., Alves, A., Gómez, J. P., Weesakul, S., Keerakamolchai, W., Meesuk, V., & Sanchez, A. (2021). Effectiveness of small- and large-scale Nature-Based Solutions for flood mitigation: The case of Ayutthaya, Thailand. *Science of the Total Environment*, *789*, 147725. https://doi.org/10.1016/j.scitotenv.2021.147725

Adoption of ecohydrology approaches for urban stormwater management and advancing the circular economy concept

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Keywords: urban stormwater, stormwater reuse, ecohydrology, circular economy

ABSTRACT

Urban stormwater runoff is of concern due to the potential to contribute to the degradation of receiving water quality and an increase in flood risk (Wang et al., 2022). It is a major source of pollutants such as nitrogen, phosphorous, heavy metals and hydrocarbons to urban water bodies. Urbanisation results in the conversion of pervious surfaces to impervious surfaces in the form of roads and roofs which in turn leads to an increase in surface runoff and greater potential for flooding (Pour et al., 2020).

However, from the perspective of sustainable development, stormwater is a potential water resource to overcome the ever-increasing water scarcity being experienced in urban areas around the world (Wijesiri et al., 2020). It can be reused for a range of purposes after appropriate treatment and thereby reduce the demand on natural resources for the supply of water (Ma et al., 2019). Therefore, the sustainable management of stormwater is important to reduce stormwater pollution as well as to enhance its reuse as an alternative resource.

Current urban stormwater management strategies primarily focus on the environmental impact on receiving waters rather than considering stormwater as an alternative water resource after undergoing appropriate treatment (Ishaq et al., 2023; Suresh et al., 2023; Zhuang et al., 2023). This linear management of stormwater leads to a growing demand for green infrastructure such as stormwater treatment facilities on the one hand and waste collection within stormwater infrastructure such as sediments and nutrients on the other hand. For example, low impact development (LID) practices in China or Water Sensitive Urban Design (WSUD) practices in Australia are commonly applied to mitigate stormwater pollution. The implementation and maintenance of these systems can impose a high environmental and economic burden (Xu et al., 2019).

The capture and reuse of urban stormwater can form a key component of integrated urban water management (Mankad et al., 2019). For example, it has been found that the volume of stormwater runoff in major Australian cities typically exceeds the volume of water drawn from their centralized catchments and groundwater sources (Coombes et al., 2007). Refer to Figure 1 below. Therefore, the prudent management of urban stormwater would entail minimal ‘import’ of water into Australia’s urban fabric. Further, the reuse of stormwater will not only provide an alternative water supply source, but will prevent the degradation of water resources which results from the discharge of stormwater.

However, a primary focus on stormwater reuse requires a paradigm shift in urban stormwater management strategies. The concepts of ecohydrology and the circular economy will help to contextualise this paradigm shift in urban stormwater management. UNESCO provides the definition, “Ecohydrology uses the understanding of relationships between hydrological and biological processes at different scales to improve water security, enhance biodiversity and further opportunities for sustainable …”. The adoption of ecohydrology approaches is proposed for developing nature-based solutions to manage urban stormwater. Ecohydrology provides a platform for integrating a range of disciplines including social and cultural and for achieving transdisciplinarity in spatial planning and natural resources management. The multifunctional framework that ecohydrology provides can address several urban challenges such as climate change adaptation, water pollution mitigation, biodiversity loss and mitigation of the loss of ecological services (Zalewski et al., 2018). Further, it provides the basis for the integration of grey and blue-green infrastructure to achieve sustainable outcomes.

The broader benefits of ecohydrology in the urban context are:

- Water – managing the urban water cycle
- Biodiversity – aquatic ecosystems as biodiversity refugia
- Ecosystem services – blue-green infrastructure for improving human well-being/ microclimate
- Resilience – reducing greenhouse gas emissions/ reducing ecological footprint
- Culture & Education – protecting water resources as part of cultural heritage**Acknowledgements**

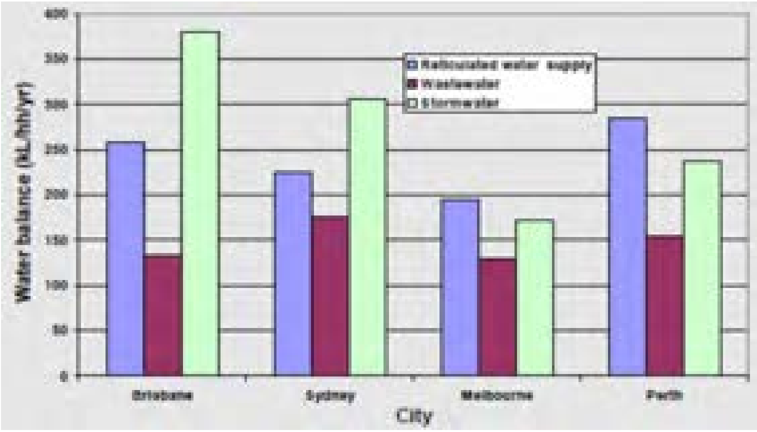

Figure 1: Comparison between water consumption and stormwater and wastewater generated in major Australian cities (Coombes et al. 2007)

Multifunctionality offered by ecohydrology enables cities to achieve a circular economy (CE) in relation to water resources management. It will enable moving from the current linear management of urban stormwater to circular management and thereby achieve sustainability in urban stormwater management. CE can be defined as an approach to achieving economic growth without increasing the consumption of new resources and reducing the impact on the environment (Dale et al., 2021). It will enable restoring the urban water cycle to the pre-urbanisation level (Atanasova et al., 2021).

In summary, the adoption of ecohydrology approaches for urban stormwater management and thereby advancing the circular economy concept will enable:

- Creating Resilient/Sustainable Cities (meeting UN's SDGs and the Sendai Framework for Disaster Risk Reduction)
- Overcome knowledge gaps on interactions between hydrological and ecological systems
- Addressing major urban circularity challenges based on the circular economy concept
- Acceptance that ecology and economics should share a co-operative and not competitive space
- Helping to understand the role that peri-urban areas can play in improving urban sustainability

References:

Atanasova, N., Castellar, J.A.C., Pineda-Martos, R., Nika, C.E., Katsou, E., Istenič, D., Pucher, B., Andreucci, M.B., Langergraber, G., 2021. Nature-based solutions and circularity in cities. Circular Economy and Sustainability 1 (1), 319-332. https://coi.org/10.1007/s43615-021-00024-1.

Coombes et al. 13th International Rainwater Catchment Systems and 5th International Water Sensitive Urban Design Conference, 2007

Costello, D.M., Hartung, E.W., Stoll, J.T., Jefferson, A.J., 2020. Bioretention cell age and construction style influence stormwater pollutant dynamics. Sci Total Environ 712, 135597. https://coi.org/https://doi.org/10.1016/j.scitotenv.2019.135597.

Dale, G., Dotro, G., Srivastava, P., Austin, D., Hutchinson, S., Head, P., Goonetilleke, A., Stefanakis, A., Junge, R., Fernández L., J.A., Weyer, V., Truter, W., Bühler, D., Bennett, J., Liu, H., Li, Z., Du, J., Schneider, P., Hack, J., Schönborn, A., 2021. Education in ecological engineering—a need whose time has come. Circular Economy and Sustainability 1 (1), 333-373. https://coi.org/10.1007/s43615-021-00067-4.

Ishaq, S., Rana, A., Hewage, K., Li, J., Sadiq, R., 2023. Environmental impacts and cost analysis of low impact developments in arid climate: a case study of okanagan valley (canada). J Clean Prod 419, 138226. https://coi.org/https://doi.org/10.1016/j.jclepro.2023.138226.

Langergraber, G., Castellar, J.A.C., Pucher, B., Baganz, G.F.M., Milosevic, D., Andreucci, M., Kearney, K., Pineda-Martos, R., Atanasova, N., 2021. A framework for addressing circularity challenges in cities with nature-based solutions, Water. https://doi.org/10.3390/w13172355

ER -.

Li, J., Culver, T.B., Persaud, P.P., Hathaway, J.M., 2023. Developing nitrogen removal models for stormwater bioretention systems. Water Res 243, 120381. https://coi.org/https://doi.org/10.1016/j.watres.2023.120381.

Ma, Y., Deilami, K., Egodawatta, P., Liu, A., Mcgree, J., Goonetilleke, A., 2019. Creating a hierarchy of hazard control for urban stormwater management. Environ Pollut 255. https://coi.org/10.1016/j.envpol.2019.113217.

Mankad, A., Walton, A., Gardner, J., 2019. Psychological predictors of public acceptance for urban stormwater reuse. J Hydrol (Amst) 572, 414-421. https://coi.org/https://doi.org/10.1016/j.jhydrol.2019.03.018.

Pour, S.H., Abd Wahab, A.K., Shahid, S., Asaduzzaman, M., Dewan, A., 2020. Low impact development techniques to mitigate the impacts of climate-change-induced urban floods: current trends, issues and challenges. Sustain Cities Soc 62. https://coi.org/10.1016/j.scs.2020.102373.

Suresh, A., Pekkat, S., Subbiah, S., 2023. Quantifying the efficacy of low impact developments (lids) for flood reduction in micro-urban watersheds incorporating climate change. Sustain Cities Soc 95, 104601. https://coi.org/https://doi.org/10.1016/j.scs.2023.104601.

Wang, J., Meng, Q., Zou, Y., Qi, Q., Tan, K., Santamouris, M., He, B., 2022. Performance synergism of pervious pavement on stormwater management and urban heat island mitigation: a review of its benefits, key parameters, and co-benefits approach. Water Res 221, 118755. https://coi.org/https://doi.org/10.1016/j.watres.2022.118755.

Wijesiri, B., Liu, A., Goonetilleke, A., 2020. Impact of global warming on urban stormwater quality: from the perspective of an alternative water resource. J Clean Prod 262, 121330. https://coi.org/https://doi.org/10.1016/j.jclepro.2020.121330.

Xu, C., Jia, M., Xu, M., Long, Y., Jia, H., 2019. Progress on environmental and economic evaluation of low-impact development type of best management practices through a life cycle perspective. J Clean Prod 213, 1103-1114. https://coi.org/https://doi.org/10.1016/j.jclepro.2018.12.272.

Zalewski, M., Arduino, G., Bidoglio, G., Junk, W., Cullmann, J., Uhlenbrook, S., Xia, J., de Leaniz, C.G., Rowinski, P.M., Vörösmarty, C.J., Chicharo, L., 2018. Low cost, nature-based solutions for managing aquatic resources: integrating the principles of ecohydrology and the circular economy. Ecohydrol Hydrobiol 18 (4), 309-310. https://coi.org/https://doi.org/10.1016/j.ecohyd.2018.12.001.

Zhang, Z., Tian, W., Liao, Z., 2023. Towards coordinated and robust real-time control: a decentralized approach for combined sewer overflow and urban flooding reduction based on multi-agent reinforcement learning. Water Res 229, 119498. https://coi.org/https://doi.org/10.1016/j.watres.2022.119498.

Zhuang, Q., Li, M., Lu, Z., 2023. Assessing runoff control of low impact development in hong kong's dense community with reliable swmm setup and calibration. J Environ Manage 345, 118599. https://coi.org/https://doi.org/10.1016/j.jenvman.2023.118599.

Advancing Nature-Based Solutions for the management of Water Quality Under the umbrella of the UNESCO IHP Ecohydrology Programme: Case study of Pilica River Catchment in Poland

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Keywords: ecohydrology, water quality, water management, Nature-Based Solutions

ABSTRACT

There is an urgent need to accelerate the implementation of the water-related Sustainable Development Goals through water science and education. In this regard Nature-Based Solutions (NBS) have great potential with growing evidence of successful implementation (e.g. Krauze and Wagner, 2019; Kalantari et al., 2023). However, investment in green technologies in the entire water sector is still below 1% (WWDR, 2018). Therefore, there is a vital need to demonstrate the advantages of NBS for water quality management and at the same time identify the weak points that require addressing from the research community.

Among strategies of water resources management, ecohydrology (EH) is the one gaining momentum. The evolution of the EH paradigm has started within the UNESCO Intergovernmental Hydrological Programme (UNESCO IHP), when the concept of “using ecosystem processes as management tools” was defined (Zalewski et al. 1997). The wide scope of EH covers processes from the molecular to the catchment scales, to identify challenges and propose innovative solutions, that follows evolutionary shaped abiotic-biotic interactions. EH creates a framework for the implementation of NBS, but also supports systemic improvement in the water quality and quantity, biodiversity and bioproductivity, ecosystem services and resilience in the catchments (Zalewski, 2014).

One of the breakthrough steps in the EH sustainable water management, was the introduction of the global demonstration sites network under UNESCO IHP, which integrates specific sites and projects that fit the scheme of EH. Currently there are 37 demonstration sites in 26 countries. Those sites, with gathered experience, will be an important reference point for the identification of new challenges and the development of NbS and systemic solutions in the context of the strategy and priorities of UNESCO-IHP Phase IX (2022-2029) "Science for a Water Secure World in a Changing Environment".

The new sustainable approach for water resources is extremely important, as with a greater understanding of biogeochemical cycles, and in concert with ecological engineering (Mitsch and Jorgensen, 1989), the EH approach can be used to support the development and implementation of NBS. The importance of NBS was thoroughly discussed in the 2018 World Water Development Report (WWDR, 2018) and has been closely linked to the concept of EH in a number of studies (e.g. Bridgewater, 2018 ; Zalewski et al., 2018 ; Krauze and Wagner, 2019, Jarosiewicz et al., 2022).

The aim of this study is to demonstrate the ecohydrology approach within one of the UNESCO Ecohydrology Demonstration Sites, Pilica River Catchment in Poland, in particular the design, implementation and results from the implemented NBS (Fig. 1).

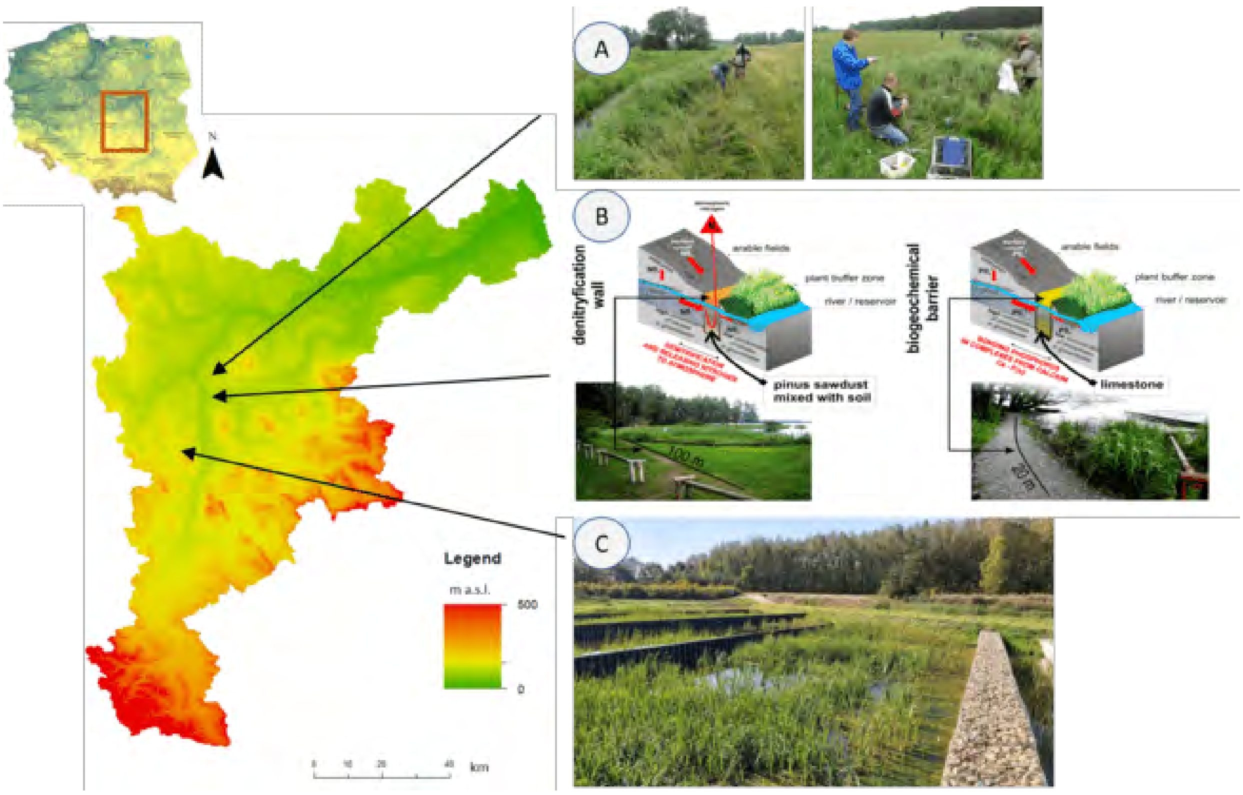

Fig. 1 Pilica catchment is located in Central Poland. Among implemented NBS are: A – riparian buffer zones; B – enhanced riparian buffer zones; C – Sequential Sedimentation Biofiltration System (SSBS).

During the LIFE EKOROB project (LIFE08 ENV/PL/000519) we studied the effects of five extensive grasslands on nitrate and phosphate reduction in the catchment scale (**Fig. 1 – A**). As observed in the catchment, multifunctional ecosystem of narrow grasslands located between croplands and streams slowly disappears from the agricultural landscape despite its importance in reducing the impact of nutrients runoff on freshwater ecosystems. During the 4-year monitoring, we did not observe the saturation effect in case of the two buffer zones that were receiving high nitrate load via subsurface flow. Highest nitrate concentration exceeded twice the level of 50 mg NO_3/L, which is considered a threshold level of water pollution status by the EU Nitrates Directive. Concentrations above 100 mg NO_3/L were reduced by 68% and 99% passing through the 25m and 45m of grassland, respectively (**Fig. 2**). The efficiency of buffer zone to mitigate phosphate losses varied depending on the input load. The results obtained for high concentrations (above 1.5 mg PO_4/L) showed 81% and 76% effectiveness of 45m and 47m grassland, respectively. However, the release of phosphates was also reported and occurred in buffer zones characterized by low inflow P concentrations when assimilation-decomposition processes dominated ecotone P dynamics. Analysis of nutrient retention in vegetation showed that grassland harvesting removed 131 kg N/ha/yr and 19.4 kg P/ha/yr (Izydorczyk et al., 2018).

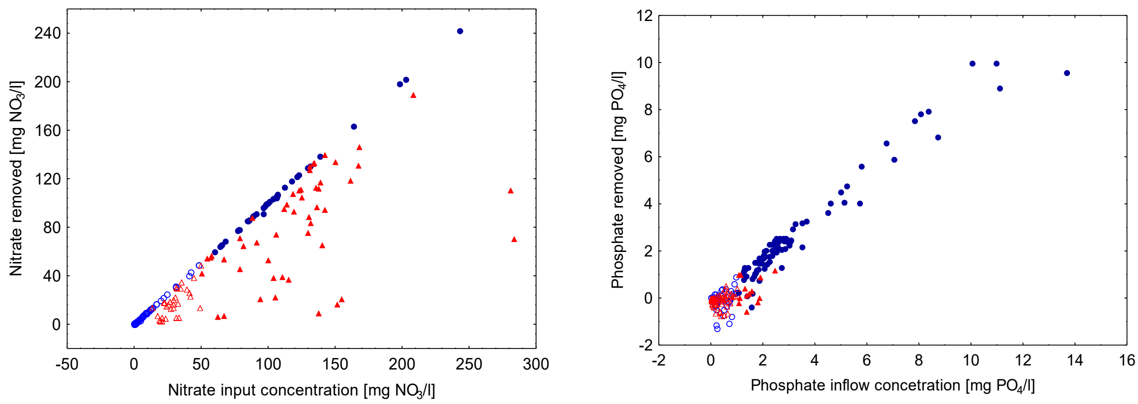

Fig. 2 Relation between input concentration of nutrients and removal efficiency of riparian buffer zone. Different shapes and colours represent different buffer zones.

Sulejów reservoir, situated on the Pilica river, is vulnerable to the toxic algae blooms and excessive eutrophication. Therefore, one of the main objectives in this area is to reduce phosphorus (P) inflow into the Sulejów reservoir by constructing a riparian plant buffer zone enhanced with a limestone barrier (**Fig. 1 – B**) along the shoreline of the reservoir. The location was selected by the high P contamination of shallow groundwater (with influent P-PO_4 concentration ranging between 0.62-4.1 mg P/L and Dissolved Phosphorus (DP) varying between 0.68-9.42 mg P/L). Firstly, a limestone-based barrier was constructed in the periodically flowing stream and its effectiveness in P removal was tested over a period of 3.5 years. P-PO_4 and DP removal effectiveness rates were found to be variable, increasing with influent concentration, but the overall long-term average effectiveness was similar for PPO_4 and DP removal, at 12.4% and 13.0%, respectively. Overall, the study provides an example of how the phosphorus recovery-and-reuse approach should be considered in improving measures for the reduction of diffuse pollution from rural areas, especially in terms of the development of NBS (Izydorczyk et al., 2013; Frątczak et al., 2019).

The Sequential Sedimentation Biofiltration System (SSBS) in Przedbórz (**Fig. – C**) is an example of ecological engineering. Its main goal is to regulate hydrological and biogeochemical processes in order to increase the intensity of self-purification processes in water ecosystems (Zalewski 2014). The SSBS area is 3700 m^2 (0.37 ha) and has a depth range from 0.2 to 1.0 m. The system consists of 3 purification zones: sedimentation, geochemical adsorption and bioremediation, according to the original proposition by Zalewski et al. (2012). In the early stage of operation SSBS was able to remove 17% of phosphates and 32% of nitrates. This system is still under evaluation with LIFE PILICA CTRL project (LIFE19 IPE/PL/000005), moreover, within the project 5 new SSSBs are planned to be implemented to mitigate the impact of urban stormwater effluent in the Pilica Catchment.

As the new threat in the catchment, we have recently identified pesticide residues. Research conducted from 2018 to 2022 revealed a large impact of orchards on the subcatchments of lower section of Pilica River. We have evidenced the correlation of orchards with pesticides presence in Rykolana river (Pilica tributary). As a result, preliminary tests have been conducted with different adsorption materials with goal to propose new advancements of NBS. The new material, BioKer, modified with activated carbon and biochar, has showed highest efficiency in MCPA removal, the herbicide which was detected the most frequently in studied area (68% of samples; n = 144). Results are presented in **Fig. 2**.

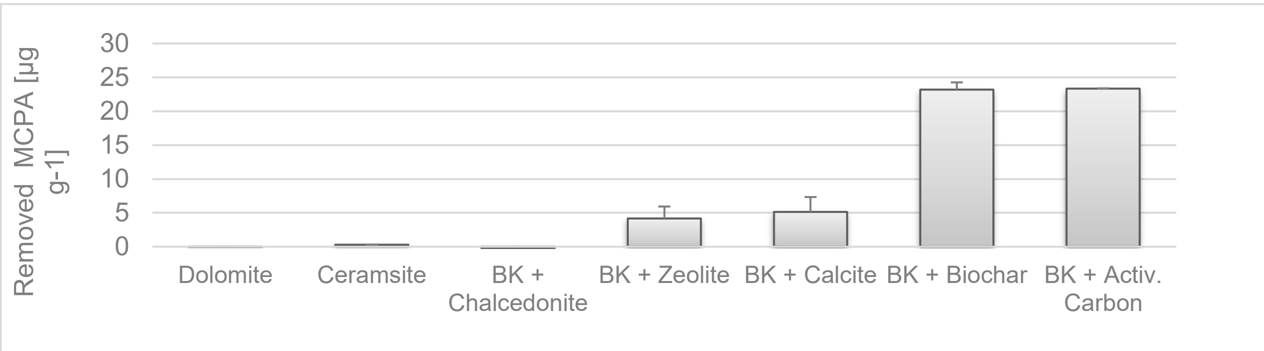

Fig. 2 Efficiency of tested materials towards MCPA in 50 µg/l concentration. BK means BioKer – material developed in 2018 (Jarosiewicz and Zalewski, patented in 2021).

Conclusions

NBS can significantly improve water quality and play a crucial role in water resources management. The Pilica River Catchment Demonstration Site is a practical laboratory for ecohydrological and NBS research. In recent years, one of the biggest challenges has been actively involving local stakeholders in the selection, implementation, and maintenance of NBS. Another issue is the saturation time, particularly with P pollution, which requires our attention. Lastly, the presence of emerging contaminants has been confirmed as a new threat. Some preliminary tests have shown that it is possible to remove pesticides with new sorption materials, which is a new element of Ecohydrological NBS (Jarosiewicz et al., 2022).

In this presentation, only one part of the strategy applied in Pilica Catchment is presented – application of NBS; the initial step should be to reinforce policy and enforce law, supported by training and education. For instance, it is important to take legal action to prevent the conversion of extensive grasslands into croplands. It should be noted that the improvement of the quality of small agricultural catchments must include a systemic approach involving various stakeholders in order to achieve a sustainable future and good quality of water resources in rivers like the Pilica, or in reservoirs.

Acknowledgements

This research was conducted in the area of Pilica Catchment UNESCO Ecohydology Demonstration Site under the LIFE EKOROB project (LIFE08 ENV/PL/000519), Przedbórz Municipal Project and IP LIFE PL Pilica basin CTRL project (LIFE19 IPE/PL/000005).

References:

Bridgewater, P. (2018). Whose nature? What solutions? Linking Ecohydrology to Nature-based solutions. Ecohydrology & Hydrobiology, 18(4), 311-316.

Frątczak, W., Michalska-Hejduk, D., Zalewski, M., & Izydorczyk, K. (2019). Effective phosphorous reduction by a riparian plant buffer zone enhanced with a limestone-based barrier. Ecological Engineering, 130, 94-100.

Izydorczyk, K., Frątczak, W., Drobniewska, A., Cichowicz, E., Michalska-Hejduk, D., Gross, R., & Zalewski, M. (2013). A biogeochemical barrier to enhance a buffer zone for reducing diffuse phosphorus pollution—preliminary results. Ecohydrology & Hydrobiology, 13(2), 104-112.

Izydorczyk, K., Michalska-Hejduk, D., Jarosiewicz, P., Bydałek, F., & Frątczak, W. (2018). Extensive grasslands as an effective measure for nitrate and phosphate reduction from highly polluted subsurface flow–Case studies from Central Poland. Agricultural Water Management, 203, 240-250.

Izydorczyk, K., Piniewski, M., Krauze, K., Courseau, L., Czyż, P., Giełczewski, M., ... & Frątczak, W. (2019). The ecohydrological approach, SWAT modelling, and multi-stakeholder engagement–A system solution to diffuse pollution in the Pilica basin, Poland. Journal of environmental management, 248, 109329.

Jarosiewicz, P., Fazi, S., & Zalewski, M. (2022). How to boost Ecohydrological Nature-Based Solutions in water quality management. Ecohydrology & Hydrobiology, 22(2), 226-233.

Kalantari, Z., Ferreira, C. S. S., Pan, H., & Pereira, P. (2023). Nature-based solutions to global environmental challenges. Science of The Total Environment, 880, 163227.

Krauze, K., & Wagner, I. (2019). From classical water-ecosystem theories to nature-based solutions—Contextualizing nature-based solutions for sustainable city. Science of the total environment, 655, 697-706.

Mitsch, W.J. , Jørgensen, S.E. , 1989. Ecological engineering: an introduction to ecotechnology. United States .

WWAP (2018) The United Nations World Water Development Report 2018: Nature-based Solutions. Paris, UNESCO.

Zalewski M. (2014) Ecohydrology and hydrologic engineering: regulation of hydrology-biota interactions for sustainability Journal of Hydrologic Engineering DOI: 10.1061/(ASCE)HE.1943-5584.0000999.

Zalewski M., Janauer G.A., Jolankai G. (1997) Conceptual background. in: Zalewski M., Janauer G.A., Jolankai G. (Eds). Ecohydrology: A new paradigm for the sustainable use of aquatic resources. International Hydrobiological Programme UNESCO, Paris, Technical Document in Hydrology 7.

Zalewski, M. (2000). Ecohydrology—the scientific background to use ecosystem properties as management tools toward sustainability of water resources. Ecological engineering, 16(1), 1-8.

Zalewski, M., Arduino, G., Bidogilio, G., Junk, W., Cullman, J., Ulhlenbrook, S., ... & Chicharo, L. (2018). Low cost, nature-based solutions for managing aquatic resources: integrating the principles of Ecohydrology and the Circular Economy. International Journal of Ecohydrology and Hydrobiology, 18(4).

Zalewski, M., Kiedrzyńska, E., Wagner, I., Izydorczyk, K., Boczek, J. M., Jurczak, T., ... & Jarosiewicz, P. (2021). Ecohydrology and adaptation to global change. Ecohydrology & Hydrobiology, 21(3), 393-410.

Science behind STORMEE - STORMwater Environmental Efficiency toolkit: 1) infiltration basin

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Keywords: infiltration basin, design storm, stormwater retention, urban hydrological cycle

ABSTRACT

Introduction. When designing the road drainage system special attention is given to environmental protection, which requires the removal of potentially hazardous elements via separators to the required degree, usually defined by the local stakeholders and legislation. Afterwards, water is simply transferred to a nearby convenient recipient. Modern engineering practice however dictates the design of sustainable drainage systems (SuDS) for the collected water, which need to provide attenuation of the runoff and must be designed to mimic the natural catchment conditions with as little disruption of natural processes as possible [1]. SuDS are designed to maximize opportunities and benefits that can be secured from surface water management: water quantity, water quality, amenity and biodiversity [2]. Construction of roadside infiltration basins is one of the measures used for these purposes. Infiltration basins are relatively simple engineering objects designed and constructed as excavations with a corresponding filter layer at the bottom (gravel or crushed stone) [3]. Essentially, they are retention spaces for permanent water retention that receive collected stormwater runoff and drain it slowly into the surrounding soil. Retention space of infiltration basin provides a reduction in the maximum peak runoff value [4], while runoff quality is also improved by filtration through the filter layer and soil. There are number of similar type objects that can be used for this purpose, applicable to different sizes and types of surface purpose (residential, parking lots, etc.) [2]. The main advantages of infiltration basins' application are 1) the relatively inexpensive cost of construction, 2) low space usage and 3) possibility of application in areas where there is no conventional stormwater sewer network or river that could serve as a recipient of stormwater runoff. This makes them particularly suitable for construction next to the roads of significant importance such as highways [5]. The retention of runoff contaminants using infiltration basins have been proven through the testing of such facilities after many years of use [6]. On the other hand, inefficiency in the operation of infiltration basins can be caused by the construction on land of poor water permeability and high groundwater levels. The stability of the surrounding structures can also be compromised given that infiltration increases the moisture of the surrounding soil [7]. Over time, there may be a decrease in the efficiency of infiltration due to clogging of the filter layer, caused by sedimentation of suspended particles. A common mistake being made in the design procedure is wrongful selection of the design storm for sizing the infiltration basin, i.e. the same design storm is used both for the collection system and the infiltration basin. Short duration, high intensity design storms are used for the design of the collection system as they result in maximum runoff peak values. Long duration, low intensity design storms should be used for the design of the infiltration basin itself as they result in much greater runoff volume which is essential for sizing of the infiltration basin.

To ensure the efficiency and sustainable functioning of the infiltration basin, design procedure should carefully address the following: 1) selection of the proper design storm and 2) all aspects relevant for soil infiltration. Basic guidelines and recommendations for the design of similar type objects can be found in literature but are lacking in detailed description of the design procedure and infiltration calculation ([2], [8]). This paper presents a comprehensive methodology for the design and operational analysis of infiltration basins for road runoff that is incorporated into STORMEE – STORMwater Environmental Efficiency toolkit. Presented methodology encompasses all relevant hydrological and hydraulic analyses in detail, which overcomes the shortcomings present in currently available regulations and design guidelines, and is packed into a user-friendly interface. Showcased here is the analysis of a field scale infiltration basin

intended for runoff control from the section of the railway in Serbia. STORMEE allows the user to efficiently perform analyses for different input data and investigate alternative designs.

Methodology. The methodology presented in this paper consist of three distinctive parts:

1) Generation of the design storm,
2) Generation of the design inflow hydrograph into the infiltration basin and
3) Calculation of time dependent infiltration and water level changes in the infiltration basin.

Hydrological analyses present the basis for the selection of the design storm and resulting stormwater runoff to be used for the design of road drainage systems. The use of constant intensity design storms for longer rainfall durations is not recommended, as it lacks naturally observed rapid fluctuations in rainfall intensity and this can lead to underestimated design flows. Therefore, it is necessary to define design storms that would result in more reliable and realistic design hydrographs. For this purpose, alternating block method is applied here. Method is based on locally available IDF curves and allows the definition of the design storms for all durations shorter than 24 hours. Adequate block size, or time interval, is selected first (Δt). Then, for all durations D_k= Δt, 2Δt, 3Δt,… rainfall intensities i_k are determined from the IDF curve. Corresponding precipitation depths (P_K) are determined as $P_k=i_k*D_k$. Incremental precipitation depth (ΔP) for each duration D_k is then derived as difference. Design storm hyetograph is created by placing the maximum incremental precipitation (ΔP_{max}) in the centre of hyetograph and remaining arranged in descending order alternating right and left. User is given the option to alter the distribution of the rainfall by changing the time position of the maximum incremental precipitation (ΔP_{max}). This is done through r_factor input value which takes values in the range [-1,1].

To generate infiltration basin's input hydrograph, it is necessary to perform modelling of rainfall-runoff process. A simple linear reservoir model is used here to transform the previously generated design storm hyetograph to corresponding storm runoff from the road. Linear reservoir model assumes linear relationship between the reservoir volume (*S*) and its' outflow (Q_{inflow}). Balance equation for linear reservoir is rearranged to solve for unknown reservoir volume at time *t* (*S(t)*) and then integrated in [t-Δt, t] interval to yield the average outflow from the reservoir, i.e. the inflow to the infiltration basin (Q_{inflow}):

$$\overline{Q_{inflow}} = \frac{S(t\text{-}\Delta t)}{\Delta t}\left(1\text{-}e^{-\Delta t/T_c}\right) + A_c C_{roff}\, \mathrm{i}\left(1\text{-}\frac{1\text{-}e^{-\Delta t/T_c}}{\Delta t/T_c}\right)$$

where *Tc* is time of concentration [s], A_c is road catchment area [m²], C_{roff} is runoff coefficient [-], and *i* is rainfall intensity [m/s]. The product $A_cC_{roff}i$ is essentially effective rainfall that is being transformed into infiltration basins' inflow hydrograph.

As previously stated, infiltration basins are usually designed and constructed as simple excavations with filter layer on the bottom to allow infiltration through the bottom. If natural topsoil layer permeability is not high enough to provide sufficiently effective infiltration through the bottom, additional boreholes that will penetrate to the lower layer, with better filtration characteristics, can be constructed at the bottom of infiltration basin (Figure 1). Infiltration basin can also be designed with emergency weir (e.g. to existing sewer network) to prevent uncontrolled overflow. After generation of inflow hydrograph, following processes are modelled in the infiltration basin:

1) Infiltration through the bottom of the basin (Q_{inf}),
2) Infiltration through the boreholes in the bottom of the basin (Q_b) and
3) Weir overflow (Q_w).

Infiltration through the bottom of the basin is calculated based on the modified Green-Ampt (GA) method which assumes a homogeneous soil with constant hydraulic conductivity (K_f), initial water content (θ_0), and head at the wetting front. The saturated wetting front is assumed to move downwards as a single piston and its' position is denoted with y(t), measured from the bottom of infiltration basin. The modification of the original GA method refers to the introduction of a time-changing ponding depth (H(t)) which allows for continuous calculation of the wetting front position, without changes in the boundary conditions at every time step [9]. Resulting equation for the wetting front position is a non-linear one and it is solved using Newton-Raphson method, after which infiltration (Q_{inf}), dependant on water level in infiltration basin (H(t)) and soil characteristics, is calculated as:

$$Q_{inf}(\overline{H})=(y(t)-y(t-\Delta t))(p-\theta_0)\frac{\overline{F}}{\Delta t}$$

where p is the soil porosity [-] and F is the average water surface area [m^2].

Equation for modelling of infiltration through the borehole (Q_b) is simply derived from Darcy's low of filtration and borehole geometry:

$$Q_b(\overline{H})= K_{f,BL}\pi D_b(\overline{H}-GWL)$$

where $K_{f,BL}$ is hydraulic conductivity of the bottom soil layer [m/s], *GWL* is static ground water level [m] and D_b is borehole diameter [m]. For the modelling of the weir overflow (Q_w) it is necessary to provide a flow-head (Q-H) curve for the weir.

Finally, the water level in infiltration basin (H(t)) can be calculated from the balance equation:

$$\overline{F}\frac{H(t)-H(t-\Delta t)}{\Delta t}=\overline{Q_{inflow}}-\left[Q_{inf}(\overline{H})+Q_b(\overline{H})+Q_w(\overline{H})\right]$$

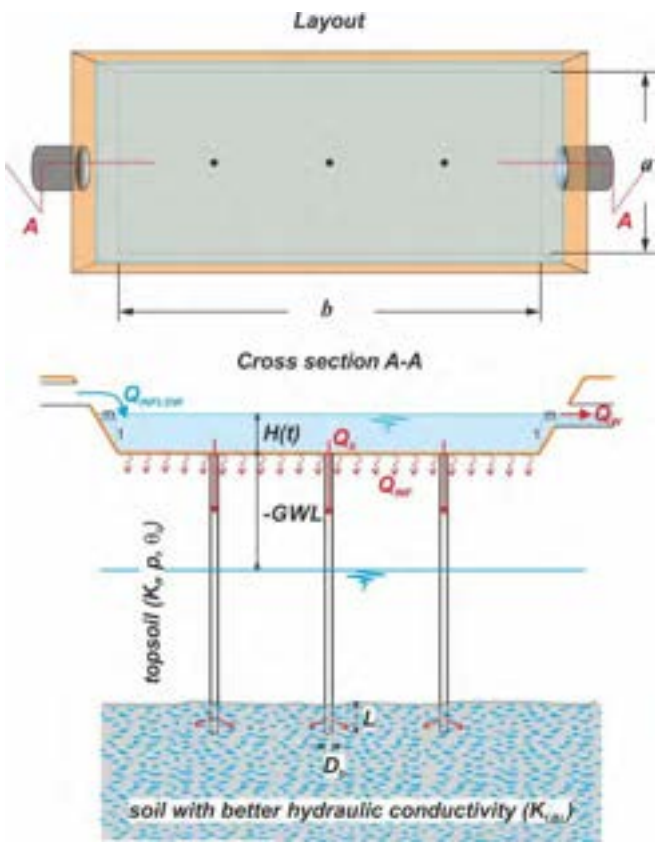

Figure 1. General layout and cross section of infiltration basin

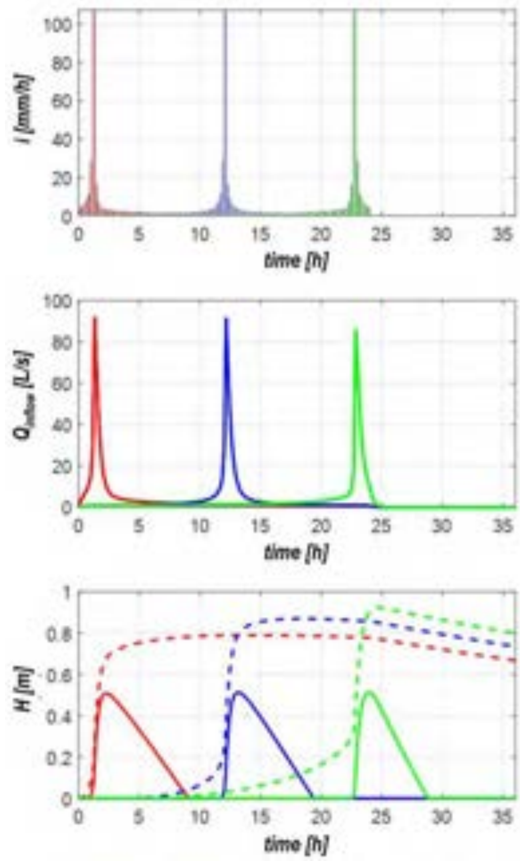

Figure 2. STORMEE outputs: Operational analyses for the designed infiltration basin

Results & Discussion. The previously described methodology for calculation and analysis of the infiltration basin is implemented in an integrated software tool that relies on: 1) MATLAB software functionality to perform all necessary calculations and graphical interpretations and 2) integration of the former into the EXCEL software for user interaction, i.e. data input and review of the results.

Presented methodology is tested on a field scale infiltration basin designed on the side of a railway corridor in Serbia. Available input data included: 1) geometric data for the designed infiltration basin, 2) soil characteristics 3) GW levels and 4) local IDF curve. Total railway catchment area gravitating to this infiltration basin is A_C= 6630 m2 and time of concentration is Tc=17.5 min, determined based on FAA equation [10]. Maximum designed allowable water level in the infiltration basin is Hmax=0.8 m and the ground water level is 2.0 m bellow the ground. Operational analysis of the designed infiltration basin has been investigated for three 24-hour 10-year design storms with different temporal distributions represented through the r_factor (r_factor=-0.9, 0 and 0.9) to assess the proposed basin design and investigate its' functionality. For the design of storm hyetograph time interval Δt=10 min is adopted. Results of the analysis are shown in figure 2 – top graph shows three different design storms, middle one shows resulting inflows into the infiltration basin and bottom one shows simulated water levels in the infiltration basin. Dotted lines refer to infiltration basin without boreholes at the bottom and solid lines refer to construction of the basin with six identical boreholes at the bottom of diameter Db=400 mm.

Presented STORMEE results on the bottom graph (H) suggest that water level in the basin will exceed maximum allowable value of 0.8 m for two of the three designed storms (r_factor = 0 and 0.9), which will result in infiltration basin overflow. Additionally, it can be concluded that water infiltration through the topsoil of relatively low hydraulic conductivity (K_f=1.5x10^{-6} m/s) is very slow, and it can take several days, questioning basins' ability to accept runoff from consecutive rainfalls. Contrary to this, simulation results for case where 6 boreholes are constructed in the bottom of the basin show that for all design storms maximum achieved water level is H=0.52 m and infiltration time after the rainfall is reduced to reasonable 4-7 hours.

Acknowledgment:

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References:

[1] M. E. Dietz, "Low impact development practices: A review of current research and recommendations for future directions," *Water. Air. Soil Pollut.*, vol. 186, no. 1–4, pp. 351–363, 2007.

[2] CIRIA, *The SUDS manual*. London: CIRIA, 2015.

[3] N. R. Siriwardene, A. Deletic, and T. D. Fletcher, "Clogging of stormwater gravel infiltration systems and filters: Insights from a laboratory study," *Water Res.*, vol. 41, no. 7, pp. 1433–1440, 2007.

[4] L. Mohd Sidek, K. Treasure Takara, and A. Ab Ghani, "Evaluation of infiltration engineering and storage tank systems For improved stormwater management," in *International Conference on Urban Hydrology for the 21st Century, Kuala Lumpur*, 2002, no. October, pp. 535–548.

[5] G. A. Burton Jr. and R. Pitt, *Stormwater Effects Handbook A Toolbox for Watershed Managers, Scientists, and Engineers*. Boca Raton: CRC Press, 2001.

[6] P. S. Mikkelsen, M. Häfliger, M. Ochs, J. C. Tjell, P. Jacobsen, and M. Boller, "Experimental assessment of soil and groundwater contamination from two old infiltration systems for road run-off in Switzerland," *Sci. Total Environ.*, vol. 189–190, no. 96, pp. 341–347, 1996.

[7] E. Alfakih, S. Barraud, and I. Martinelli, "A study of stormwater infiltration system feasibility and design," *Water Sci. Technol.*, vol. 39, no. 2, pp. 225–231, 1999.

[8] New Jersey Department of Environmental Protection, "Chapter 10.2: Infiltration Basins (Large Scale)," in *New Jersey Stormwater Best Management Practices Manual*, New Jersey Department of Environmental Protection, 2004.

[9] Z. Vasilić, A. Randjelović, D. Pavlović, M. Stanić, and D. Prodanović, "Modifying the Green-Ampt Method to Model Different Types of Infiltration Systems," in *14th IWA/IAHR International conference on Urban Drainage*, 2017, pp. 1065–1067.

[10] V. Te Chow, D. R. Maidment, and L. W. Mays, *Applied Hydrology*. McGraw-Hill, Inc., 1988.

Sub-Calibration of Soil Moisture Sensors for Stormwater Management

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Keywords: soil moisture sensor, sub-calibration, stormwater management

ABSTRACT

Introduction

Accurate soil moisture monitoring is essential for effective stormwater management, for urban and semi-urban environments where runoff and flooding can cause significant damage, disruption and even danger. Low-cost, remote soil moisture sensors could play an important role in making stormwater management more effective and sustainable, however there remain many challenges in calibrating existing sensors. Knowledge of a soil's capacity to infiltrate, conduct and sore water is an important parameter to assess its ability to manage stormwater runoff and rain; this is particularly the case in urban and semi-urban areas (Johnson, Smith & Thompson, 2018). Accurate data on local soil infiltration-related parameters is essential when assessing the need for and design of engineered stormwater management solutions, especially such that utilize existing and constructed green infrastructure, e.g. nature-based solutions. This is especially relevant as climate-change is already affecting weather, e.g. in terms of prolonged dry periods followed by shorter but more intense rain events. Both conditions have a known impact on infiltration capacity of certain soil types (Williams, Li & Pitt, 2015). In situ-continuous soil moisture measurements can yield valuable information to aid stormwater modelling and planning of local management solutions. Sensor factory calibrations do not often reflect the unique context of local and urban soils and the fluctuating dynamics of stormwater runoff throughout a calendar year in northern latitudes, where freeze-thaw cycles are common. This issue is apparent in temperate regions, where stormwater and meltwater flooding is expected to cause increasing problems due to climate change and continued urbanisation and densification (Okkonen, Karhu, & Ala-aho, 2013).

This paper presents a sub-calibration of a low-cost, remote soil moisture sensor which was originally designed for golf course management and agricultural output optimization, but could offer an interesting solution to stormwater professionals, city planners and local governments. The objective of this sub-calibration is to determine how to use the sensors most accurately and to conclude whether these sensors should be recommended for wider use in stormwater management, primarily for temperate regions. More specifically, the sensor in question does not indicate more than 67% water content, even when fully immersed in pure water, and may therefore need to be calibrated to local soil properties to obtain meaningful data. Using the factory calibrations for the devices yields a relative actual moisture content, so a recalibration is necessary to acquire readings that reflect actual soil moisture content, which is important for hydrological analysis and modelling (Harter et al., 2019).

Description of the device

The sensor in question is part of a device package which includes the sensor/s, a base station, a monitoring service, and an optional echo repeater. They report data at intervals ranging from every five to fifty-five minutes via an embedded antenna. The sensors can report on capacitive moisture, temperature, and electric conductivity simultaneously and it is possible to assign up to 1,000 sensors to one base station.

The signal is received by the base station via a receiving antenna and the data is then uploaded to the unique server using a cellular modem.

The independent server conducts data validation and applies correction equations to incoming raw measurements from the sensors. Researchers can isolate individual sensors or analyse combined data from packages of sensors through the user interface. Importantly, each sensor can be adjusted through this interface to the context of its surrounding soil type. The manufacturer claims a moisture accuracy of +/-2% mean error, or +/-1% mean error when the correct soil type has been selected.

Methodology

The moisture readings of each individual sensor were compared against one another, before all sensors were calibrated through a combination of lab and field tests across a range of environmental conditions. The purpose of these tests was to see discrepancies between multiple sensors when they were situated in identical soil or water environments.

Laboratory tests in various conditions for inter-device comparisons

The first test conducted consisted of full immersion of soil scouts in various conditions, including:

- Buried 5.5cm in a known soil composition at room temperature.
- Buried 5.5cm in known soil composition at room temperature, then saturated with water.
- Submerged fully in water only.
- Buried in 5.5cm of known soil, then frozen.
- Buried in 5.5cm of known soil, then saturated with water before freezing.

Sub-calibration of moisture readings, using established moisture content tests

Test 1

The sensors were then calibrated using standardized laboratory tests. The purpose of these tests was to identify differences between actual moisture content of soil samples and the data received from the embedded sensors. Furthermore, these tests would compare *changes* to moisture content, as known amounts of water are added to a standardize soil sample at regular time intervals.

To control for the variable of soil composition, this test required a standardized soil sample. To this end, a bag of playground sand was purchased from a store. A sample of this sand was taken for a soil grain size analysis and the sensors were then set to this soil type. The standardized sand sample was first dried overnight in an oven to remove all moisture. The sensor was then installed 5cm deep in a 10cm deep sample. The next step was to apply a standardized compression to the soil, whereby a known weight was applied equally over the whole surface of the sand sample. At this stage, the whole sample was weighed.

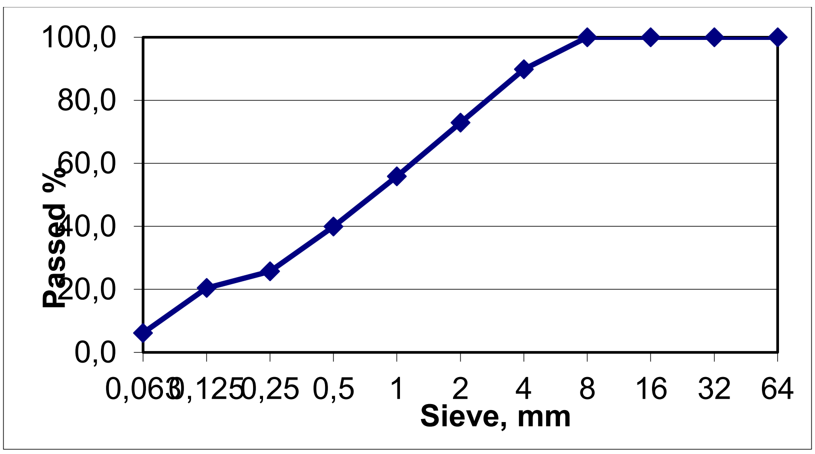

Figure 19: Soil grain size analysis for the soil sample used in sensor sub-calibration. The graph indicates the distribution of grain size within the sample.

Once per hour, a known amount of water was added to the sample. The water was added using a watering can with a sprinkler head, to ensure that water could be dispersed gently and evenly over the whole of the sand surface. Water was added in this way until the sample was fully saturated, which was determined as the point at which water pooled on the surface of the soil sample.
By adding a known amount of water at set time periods, it was possible to calculate a moisture percentage for the whole sample. This could then be compared against the moisture reading given by the sensor.

Test 2
The second standardized sub-calibration test involved fully saturating a standardized soil sample and then tracking water loss, through evaporation, over time. The same playground sand – again, 10cm deep - was fully saturated with water, with the sensors embedded at 5cm. The sample was weighed before and after the water was added.
Next, water loss from the sample was tracked over time by weighing the sample twice per day until the sample had reached its starting (dry) weight. Daily water loss could be converted into a loss percentage, which could in turn be compared to the loss percentage reported by the embedded sensors.

Field tests
Field installation for each device followed a strict procedure, as recommended by the manufacturer. The first step is to create a map of intended locations and depths for each sensor; this map can be updated and illustrated with photographs and a note of each sensor's ID number following installation. Importantly, individual sensors have no in-built geo-tracking technology, so clear maps were made to locate each buried sensor (*figure 2)*.
The sensors were installed in field sites from November 2022-May 2023 and reported soil moisture content every twenty minutes during this period. The base station was installed at an elevated position and was powered by an external battery during periods when there was insufficient daylight for the solar panels to fulfill this function.

Figure 20: The sensors were buried in multiple outdoor locations and reported data from November 2022 - May 2023. The location of each sensor was carefully mapped, to allow the devices to be easily relocated.

Results

Inter-sensor discrepancies were found for between sensors embedded in "identical" solutions, as can be seen in *Figure 3*. One possible cause of these discrepancies is that the samples were not, in practice identical, and that variation within the samples caused these differences in readings. This interpretation is unsatisfactory, however, as the sensors reported different moisture content eve when submerged in pure water.

Occasional loses of data packages could reduce the validity of measurements over a short time series, but do not have such an impact on longer periods of monitoring.

Sensors were able to display changes in moisture content and temperature over long periods of time, however their 20-minute reporting frequency did cause delays in recognizing rapid changes in moisture content.

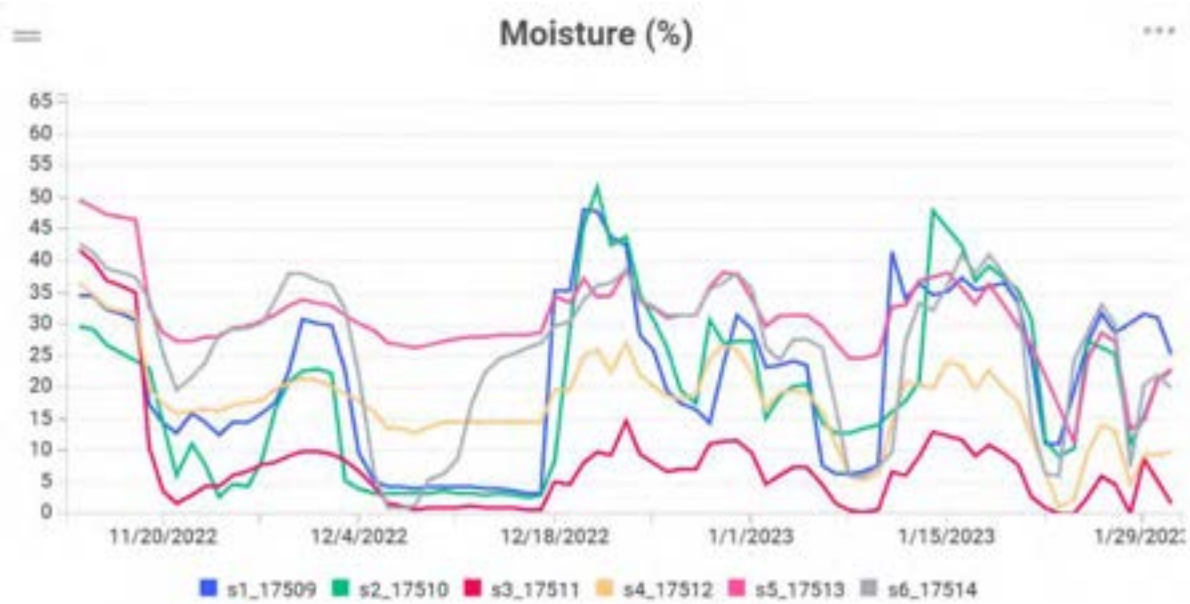

Figure 21: The online monitoring service allowed for comparison between sensors and across specified time periods. It also highlighted inconsistencies, such as data reporting gaps and disparities in reported data between multiple sensors in identical environments.

Conclusions

Several conclusions can be drawn from these calibration tests which could help water engineers, city planners and local governments monitor and manage stormwater impacts.

- Each sensor should be individually calibrated prior to field installation, as differences of up to 20% moisture content were found between sensors in identical and near-identical environmental conditions.
- The sensors are competent at illustrating changes in the moisture content of soils, however some rapid changes may be hard to observe due to the maximum reporting interval being 5 minutes.
- This type of remote sensor offers an easy-to understand overview of moisture and temperature trends but should be accompanied by traditional moisture probes for more time-specific readings.

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References:

1. Okkonen J., Karhu V., and Ala-aho P. (2013). Calibration of Capacitance Soil Moisture Sensors for Different Soil Conditions in Finnish Fields. Boreal Environment Research, 18(1-2), 57-67.
2. Okkonen J., and Karhu V. (2015). Evaluation of Calibration Methods for Capacitance Soil Moisture Sensors in Finnish Soils. Boreal Environment Research, 20(6), 679-690.
3. Schmalzried D., Casanova J., Jones S., et al. (2015). Estimating Soil Water Retention Characteristics from the Calibration of a Low-Cost Capacitance Sensor. Journal of Hydrology, 530, 379-387.
4. Johnson, A. B., Smith, C. D., & Thompson, L. K. (2018). Assessing Soil Moisture Dynamics for Improved Stormwater Management in Urban Areas. Journal of Hydrology, 556, 209-220.
5. Harter T., Hopmans J. W., Dane J. H., et al. (2019). A Simple Calibration Method for Capacitance-Based Soil Moisture Sensors. Vadose Zone Journal, 18(1), 1-10.
6. Alemu M. C., McKee M., and Gray D. (2020). Evaluation of Calibration Techniques for Capacitance Soil Moisture Sensors in a Sandy Loam Soil. Journal of Irrigation and Drainage Engineering, 146(3), 04019078.
7. Williams, R., Li, Y., & Pitt, R. (2015). Soil Moisture Monitoring Techniques for Stormwater Management: A Review. Journal of Hydrologic Engineering, 20(10).

Session B8: Constructed wetlands applications

Assessing the treatment capacity of an ecological engineered wetland receiving AMD over a period of nine years using water quality and periphyton as indicators

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Keywords: Periphyton, AMD, coal mining, phytoremediation, water quality

ABSTRACT

The Grootspruit valley bottom wetland covers an area of 135.3 ha and is heavily impacted by acid mine drainage (AMD) from an abandoned underground coal mine upstream. Due to acid mine drainage upstream, the wetland has become a channelled valley bottom wetland over space and time. It is located in the Mpumalanga Upper Olifants River catchment (Quaternary Catchment B20G) of South Africa and forms part of a larger wetland system which lies along a tributary of the Zaalklapspruit River and the Grootspruit River. The wetland has been identified as a 'National Freshwater Ecosystem Area' and falls within a 'critically endangered wetland type' The wetland has been classified as a priority wetland in a recent assessment of the conservation significance of aquatic resources, Critical Biodiversity Area (CBA). Through ecological engineering the Grootspruit wetland size was increased by 9.4 hectares to allow for gravitational drainage of AMD water in 2014. The enlargement of the wetland was through the redirection of water flow using concrete structures to enlarge the surface area of the wetland to improve water quality. The purpose of the concrete structures was to change the wetland's flow from a channeled to unchanneled valley bottom wetland. Before decanting of the abandoned mine upstream of the wetland, the wetland was classified as an unchanneled valley bottom wetland. However, the increased water volumes received from the decanting mine upstream of the wetland changed it to a channeled valley bottom wetland over time and space. This caused the deterioration of the water quality in the wetland reducing its ecosystem services (Oberholster et al., 2022).

The wetland's main channel had four intervention points, while the secondary incised channel was rehabilitated at three points. These intervention points were strategically selected to deactivate channelization of both the main and secondary incised channels, and to reduce the velocity of the water. Thus, the objectives of the study were 1) to determine through biotic and abiotic indicators whether the ecological engineered interventions helped to improve the downstream surface water quality, and (2) to determine the functional role of the groundwater- surface water interactions in the resultant water quality. At the onset of the ecological engineered intervention, the Grootspruit wetland area showed elevated metal, sulphate, and total dissolved solids (TDS) concentrations with a low average pH, all indicative of an area impacted by AMD. Over the nine years of monitoring, the inflow to the wetland was dominated by the filamentous green algal species *Klebsormidium acidophilum,* which is an indicator of acidic conditions, while the diatom *Staurosira elliptica* was the dominant species at all sampling sites except for the outflow site. The latter species is a good indicator of brackish water with elevated electrolyte content (Taylor et al., 2007). The outflow of the wetland was dominated by the green filamentous algal species *Klebsormidium rivulare* (Kützing) and the diatom species *Tabellaria flocculosa* (Roth) and *Nitzschia nana* (Grunow). After an extensive drought period during 2016, followed by a veldfire in 2020, a significant shift in periphyton species assemblage was recorded, indicating an elevation in electrolytes and nutrient enrichment of the water at the outflow site (Oberholster et al., 2022). To understand the underpinning mechanisms that groundwater-surface water interaction performs in sustaining the hydroperiod of the Grootspruit wetland for passive AMD treatment, stable isotopes were employed to determine the interaction of local groundwater resources and the overlaying wetland ecosystem. Water types for surface

water samples collected at the inflow, middle of the wetland, and the outflow of the wetland were SO_4^{2-} type (inflow); Ca-Mg-SO_4^{2-} type (middle wetland sites 2 and 3); Mg-SO_4^{2-}-CO_3^--HCO_3^- type (outflow); Na-CO_3^--HCO_3^--Cl^- type (NP1 piezometer); and Mg-CO_3^--HCO_3^- type (borehole adjacent to wetland site). The water types shows that both the inflow site and the piezometer installed 1.5 meter below the wetland sediment at the wetland inflow were affected by AMD. Additionally, the elevated Ca^{2+} and Mg^{2+} contents indicated that the middle section of the wetland could possibly be dependent on discharges of fresh groundwater with increased buffering capacity (higher HCO_3^- and CO_3^-). Water rock interactions occurring in the subsurface increased the Ca^{2+} and Mg^{2+} concentrations in shallow subsurface water. Thus, its local discharge to the wetland increased the Ca^{2+} and Mg^{2+} content in the middle of the wetland site. Furthermore, the hypothesis that shallow groundwater discharging into the wetland along its flow path is given further credence by the prevalence of buffering ions HCO_3^- and CO_3^-, which arise from water that interacts with subsurface geological material, as well as that biological activity in the soil horizon input these two anions (Chenini et al., 2010). The similarity in groundwater type from the adjacent borehole to that of water sampled within the wetland and at its inflow, suggests that locally, shallow subsurface water drains towards the wetland, providing important water resources for the wetland to withstand the desiccation during the dry period.

The obtained results over the 9 year-period confirmed that the water quality improved significantly with pH values changing from 3.4 at the inflow to 7.1 at the outflow of the wetland. The downstream sites from the inflow to the wetland outflow showed a significant decrease in sulphate (SO_4^{2-}), while alkalinity increased at the outflow. Sulphate, pH, and alkalinity determined for the reference site 2.2 km upstream from the mine, remained relatively unchanged during the sampling period, and therefore, it was un-impacted by mining practices and AMD. The pH, alkalinity, and silica concentration increased, while the electrical conductivity (EC) decreased by 35% from a median concentration of 2,470 µS cm^{-1} at the inflow to 861 µS cm^{-1} at the outflow of the wetland. The metals primarily associated with AMD, namely aluminium (Al) and iron (Fe), were reduced from the inflow to the outflow of the wetland by respectively ~94% and ~85%. The study further showed that the drought of 2016 had a bigger impact on the wetland's passive treatment capacity than the veldfire of 2020.

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References

Chenini, I., Farhat, B., Ben Mammou, A. B., 2010. 'Identification of major sources controlling groundwater chemistry from a multilayered aquifer system', Chemical Speciation and Bioavailability, 22(3), 183–189. doi: 10.3184/095422910X12829228276711.

Oberholster, P.J, Schoeman, Y., Truter, C., Botha, A-M., 2022. Using periphyton assemblage and water quality variables to assess the ecological recovery of an ecologically engineered wetland affected by acid mine drainage after a dry spell. Processes ,10, 877. https://doi.rg/10.3390/pr10050877

Efficiency of pilot scale constructed wetlands with various substrates for landfill leachate treatment

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Keywords: constructed wetlands, landfill leachate, circular economy

ABSTRACT

Introduction

Landfill leachate is a high pollutant wastewater that its treatment requires a series of physical and chemical processes. Leachate that produced in municipal solid waste (MSW) landfills consists of moisture waste, drained rain water and liquids that produced from biochemical reactions [Christansen & Vanderleyden., 1994]. The correct management of landfill leachates is a major issue for the protection of environment. So far, these wastewaters are treated with conventional methods that have been proved quite effective but come along with high financial costs and energy needs [Stefanakis et al., 2014]. The importance of this study is related to the need to develope a new more environmentally friendly technology to manage a highly polluting wastewater such as landfill leachate with sustainable methods that follow circular economy. Constructed wetlands, offers a great solution in this problem by providing low construction and operation cost, avoiding the chemical methods and are also a system fully harmonized with the natural environment.

Materials and Methods

In this study landfill leachate was treated, using four different types of pilot – scale horizontal subsurface (SF) constructed wetlands (CWs) were built at the campus area of Technical University of Crete, Chania, Greece. Gravel, recycled HDPE and biochar from olive brunches were used as substrate materials. These four equally sized beds were designed with 188L volume and a slope of 1% and were filled with gravel (G), gravel and biochar (GB), HDPE (P) and HDPE and biochar (PB) respectively and operated for eleven months. In all beds, *Phragmites australis* was selected as vegetation while periodical application of methanol was also examined. The porosity of plastic and gravel were 95% and 30% respectively (for gravel d50=7mm). As for biochar, was produced from branches of olive oil trees with diameter of 2–3cm at 400^{o}C under anaerobic conditions and it was placed approximately at the average height of the bed in amount of 10% of the unit volume.

Results and discussion

The results showed that the presence of biochar has an important role in *Phragmites Australis* growth and expansion, making GB and PB more efficient in pollutants removal and in water losses compared with the corresponding units (G and P). Furthermore, methanol addition combined with anaerobic conditions of the CWs, achieved great removal of nitrate which was the main pollutant of the leachate achieving removal 67, 86.4, 69.3, 86.2% in G, GB, P, PB respectively. COD results showed some good removal that ranged between 45–67%. Comparing these values with other studies such as the review of [Bakhshoodeh et al., 2020] who came to an average COD effluent value -for Horizontal Subsurface CWs for landfill leachate treatment - of 54.5±25%, we conclude that our results achieved a great COD removal. TSS achieved high removal between 70-85%. TSS removal is probably the result of physical processes such as sedimentation and filtration [Kadlec & Wallace 2008]. In the early phases of the experiment the efficiency of TSS removal was in lower levels compared with the followed period, this can be explained by the lower porosity of the substrate that existed at the beginning of the experiment and tends to clog with the passage of time. Removal values range is good compared with [Bakhshoodeh et al., 2020] review (69.3±17%) and [Anh et al., 2020] study (78%) for HSF CWs. In addition, removal values are higher than those of [García-Ávila, 2020] who found TSS removal 62.9±10.1% using *Phragmites αustralis* as plantation.

Parameter		IN	G	GB	P	PB
COD	(mg/L)	871.6 ± 337.1	491.6 ± 267.5	423.8 ± 313.5	326.3 ± 175.8	286.1 ± 142.6
	(%)		44.9 ± 13.5	54.6 ± 12.6	62.5 ± 15.2	67.2 ± 10.8
TSS (mg/L)	(mg/L)	181.2 ± 52.6	41.7 ± 15.3	49.4 ± 27.9	24.0 ± 15.7	23.2 ± 6.9
	(%)		74.1 ± 15.5	70.4 ± 23.9	83.6 ± 18.7	85.3 ± 8.5
NO_3 (mg/L)	(mg/L)	783.5 ± 237.6	212.2 ± 82.3	79.9 ± 57.4	193.5 ± 49.3	72.5 ± 47.1
	(%)		67.0 ± 24.3	86.4 ± 14.6	69.3 ± 22.4	86.2 ± 16.3
NO_2 (mg/L)	(mg/L)	147.1 ± 49.5	18.0 ± 15.0	3.8 ± 4.5	22.5 ± 9.4	7.6 ± 5.3
	(%)		88.3 ± 7.4	98.6 ± 1.8	84.1 ± 6.0	95.5 ± 2.8
NH_4 (mg/L)	(mg/L)	112.0 ± 41.9	23.5 ± 11.4	16.1 ± 9.5	31.5 ± 10.5	19.9 ± 6.4
	(%)		75.5 ± 18.3	83.4 ± 14.7	68.4 ± 16.2	80.6 ± 7.4
pH		6.9 ± 0.2	7.2 ± 0.3	7.4 ± 0.4	7.2 ± 0.4	7.3 ± 0.4
EC	(mS/cm)	4.7 ± 0.9	5.9 ± 0.5	5.8 ± 0.7	4.9 ± 0.4	5.1 ± 0.4

Table 1. Influent and effluent concentrations and percent removals

Conclusions

- CWs with biochar had a better performance that characterized with *Phragmites Australis* extended growth mainly in above ground biomass
- Biochar enhanced CWs nitrate removal 22.5% and 19.6% in gravel and HDPE plastic units respectively
- Anaerobic condition of HSF CWs provide ideal condition for the denitrification process to remove high nitrate concentrations from the leachate
- Methanol addition enhances denitrification process by offering an additional biodegradable carbon source in CW system and increases nitrate removal in first applying period 31.5, 17.7, 28.6, 18.6% and in second period 25.2, 13.1, 26.3, 16.5% for G, GB, P, PB respectively.

References:

Christansen-Weniger, C., & Vanderleyden, J. (1994). Ammonium-excreting Azospirillum sp. become intracellularly established in maize (Zea mays) para-nodules. *Biol. Fertil. Soils*, *17*, 1-8.

Bakhshoodeh, R., Alavi, N., Oldham, C., Santos, R. M., Babaei, A. A., Vymazal, J., & Paydary, P. (2020). Constructed wetlands for landfill leachate treatment: A review. Ecological Engineering, 146, 105725.

Kadlec, R. H., & Wallace, S. (2008). Treatment wetlands. CRC press.

García-Ávila, F. (2020). Treatment of municipal wastewater by vertical subsurface flow constructed wetland: Data collection on removal efficiency using Phragmites Australis and Cyperus Papyrus. Data in brief, 30, 105584.

Stefanakis, A., Akratos, C. S., & Tsihrintzis, V. A. (2014). *Vertical flow constructed wetlands: eco-engineering systems for wastewater and sludge treatment*. Newnes.

Use of Vertical Flow Constructed Wetlands for domestic laundry wastewater treatment with ornamental plants

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Keywords: nature-based solutions, *Trachelospermum jasminoides*, sand, unplanted, organic pollutants, treatment wetlands

ABSTRACT

Greywater, such as laundry wastewater (LWW), has a great potential for reuse due to its availability and its low concentration on pollutant load (Hernández Leal et al., 2007). Nature-based technologies such as constructed wetlands (CWs), seem to be more promising due to their low energy requirements (Boano et al., 2020). Vertical flow constructed wetlands (VFCWs), demand smaller area for their construction, exhibit higher oxygen transfer capacity and are characterized by lower construction costs (Dotro et al., 2021). Ornamental plants have established their appearance in CWs (Sandoval-Herazo et al., 2019) as they add an aesthetic value to the systems (Patil and Munavalli, 2016).

To the best of our knowledge, there is only another study of our research team, regarding the use of vertical flow constructed wetlands for particularly laundry wastewater treatment (Sotiropoulou et al., 2023). Therefore, the level of the optimal pollutant removal in VFCW systems for laundry wastewater treatment in Mediterranean climatic conditions, as a function of the presence or absence of an ornamental plant, will be evaluated.

The experiment was conducted from March 2023 until May 2023. Two identical VFCWs were installed outdoor in the campus of the University of the Aegean in Mytilene. Specifically, open plastic containers (internal width: 0.47 m, internal length: 0.65 m, internal height: 0.60 m) were filled with three layers of materials: a drainage layer (10 cm) filled with coarse gravel, a transition layer (10 cm) filled with fine gravel, and a main layer (40 cm) filled with washed sand. In the first system the ornamental plant *Trachelospermum jasminoides* was used, while the second system remained unplanted, to examine plants contribution to pollutants removal. Regarding the LWW, it was collected directly from a washing machine (from a single house permanently inhabited by five people). The washing program was set at 40 °C water temperature and conducted at 600 rpm spin-drying speed. Systems received an inflow of 0,01 m^3/d (HLR = 32.7 mm/d). Wastewater quality parameters were measured three times per week. More specifically, influent, and effluent samples were analyzed for pH, electrical conductivity (EC), total suspended solids (TSS), chemical oxygen demand (COD), total phosphorus (TP) according to APHA, (2005). Turbidity was measured using a portable Turbidity Meter (2100Q, Hach).

Laundry wastewater physical-chemical parameters are presented in **Table 1**. Results regarding the effluents of the VFCWs showed that both the planted and unplanted system had high removal efficiencies regarding turbidity (planted: 97 ± 2 %, unplanted: 98 ± 4 %), TSS (planted: 92 ± 9 %, unplanted: 97 ± 2 %) and COD (planted: 98 ± 2 %, unplanted: 98 ± 1 %) parameters. However, from the above results could be deduced that *T. jasminoides*, did not contribute to higher removal rates, while sand substrate was the main operational characteristic which contributed to such high organic pollutants removal. Electrical conductivity values of the systems effluents were a bit higher than the inlet (inlet: 1435 ± 430 μS/cm, planted: 1508 ± 495 μS/cm, unplanted: 1438 ± 434 μS/cm). Such difference especially for the planted system, could be attributed to the higher evapotranspiration of the plant compared to the unplanted and

also to the possibility that the more conducting ions remained in solution as the less conducting ions were removed from the systems. Moreover, it was also demonstrated that even though at the beginning of the operation, both systems demonstrated approximately 20 % removal of TP, after a few weeks, systems stopped removing TP.

Table 8. Physicochemical characteristics of laundry wastewater (LWW)

that was applied in this study.

Parameters	LWW **(mean number ± s.d,number of samples)**
pH	**7.3 ± 0.4 (18)**
Turbidity (FNU)	**229 ± 62 (18)**
Electrical conductivity (μS/cm)	**1435 ± 430 (18)**
TSS (mg/L)	**22 ± 11 (18)**
COD (mg/L)	**130 ± 50 (18)**
TP (mg/L)	**3.4 ± 1.0 (18)**

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References:

APHA, (2005). Standard Methods for the Examination of Water and Wastewater. American Public Health Association (APHA), American Water Works Association (AWWA), and Water Environment Federation (WEF).

Boano, F., Caruso, A., Costamagna, E., Ridolfi, L., Fiore, S., Demichelis, F., Galvão, A., Pisoeiro, J., Rizzo, A., Masi, F., 2020. A review of nature-based solutions for greywater treatment: Applications, hydraulic design, and environmental benefits. Science of The Total Environment, 711, 134731. https://doi.org/10.1016/j.scitotenv.2019.134731

Dotro, G., Langergraber, G., Molle, P., Nivala, J., Puigagut, J., Stein, O., von Sperling, M. (2021). Treatment Wetlands, IWA Publishing. https://doi.org/10.2166/9781780408774.

Hernández Leal, L., Zeeman, G., Temmink, H. and Buisman, C. (2007). Characterization and biological treatment of greywater. Water Science and Technology, 56, 193-200. https://doi.org/ 10.2166/wst.2007.572

Patil, Y.M. and Munavalli, G.R. (2016). Performance evaluation of an Integrated On-site Greywater Treatment System in a tropical region. Ecological engineering, 95, 492–500. https://doi.org/10.1016/j.ecoleng.2016.06.078

Sandoval-Herazo, L., Zamora-Castro, S., Vidal-Álvarez, M. and Marín-Muñiz, J. (2019). Role of Wetland Plants and Use of Ornamental Flowering Plants in Constructed Wetlands for Wastewater Treatment: A Review. Applied Sciences, 9, 685. https://doi.org/10.3390/app9040685

Sotiropoulou, M., Stefanatou, A., Schiza, S., Petousi, I., Stasinakis, A.S., Fountoulakis, M.S. (2023) Removal of microfiber in vertical flow constructed wetlands treating greywater. Science of The Total Environment, 858, p. 159723. https://doi.org/10.1016/j.scitotenv.2022.159723.

Small constructed wetland in Norwegian agricultural catchment – 18 years monitoring and perspectives for the future

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Keywords: Small constructed wetlands (CWs), removal efficiency, seasonal variations, sediment sources and distribution.

ABSTRACT

Introduction and objectives: Constructed wetlands (CWs) are a widely recognised measure for reducing pollution loads and improving the quality of agriculture runoff.

In Norway, free water surface CWs, with emergent vegetation treating agricultural runoff, have been used since the early 1990s as an important supplement to best management practices for water quality improvements (Direktoratsgruppa, 2009). Surface water quality problems in Norway are largely caused by high phosphorus (P) inputs from the catchments. Runoff and diffuse pollution from agricultural areas are the main sources of P input to Norwegian surface waters (Selvik et al., 2006; Øgaard et al., 2016). Since P mainly are particle bound, Norwegian CWs are therefore designed to remove suspended sediment (SS) and P through sedimentation and filtration (Fig.1).

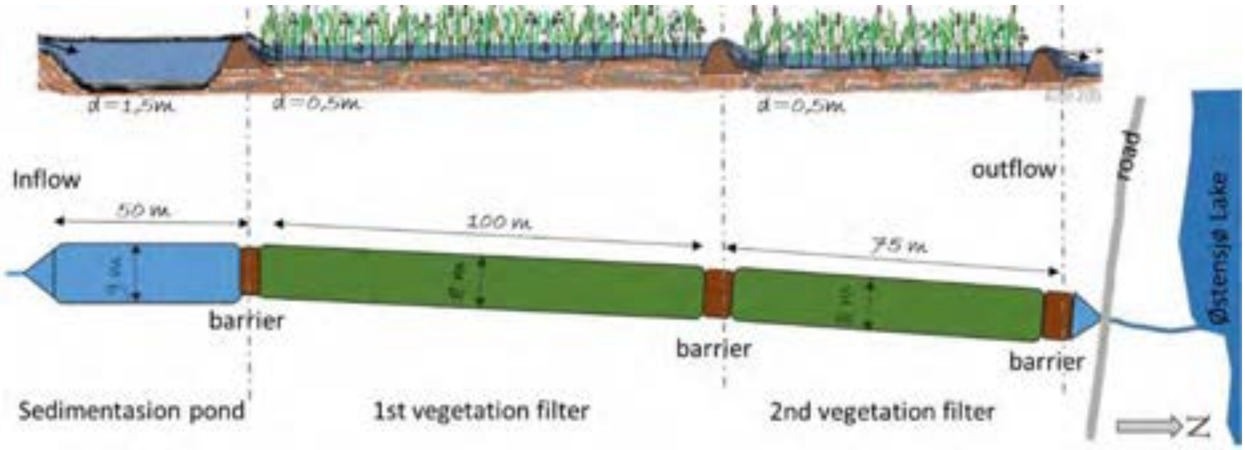

Figure 1. The components of the Skuterud CW as an example of typical Norwegian wetland design to remove suspended sediment and phosphorus (adapted from Blankenberg et al., 2016).

In 2015, there were already more than a thousand CWs established in Norway and that number is constantly growing (Blankenberg et al., 2015). However, climate change and a constantly growing need for intensification of agriculture may influence hydrological catchment responses like runoff patterns, and potentially increase erosion (surface- and bank erosion), nutrient and other pollutions like e.g. pesticides.. Consequently, the need for mitigation measures in the agricultural landscape, such as CWs, will continue to increase (Øygarden et al., 2011; Deelstra et al., 2011; Blankenberg et al., 2013).

Many studies have shown that CWs are effective also in cold climate regions (e.g., Braskerud et al., 2001; Koskiaho et al., 2003; Braskerud et al., 2005; Hauge et al., 2008; Blankenberg et al. 2007, 2013; Rozema et al., 2016; Carstensen et al., 2023). However, the removal efficiency of CWs varies considerably depending on system type and design, as well as residence time, hydraulic load, particles- and nutrient loading rates. Therefore, there is a need to closely monitor the efficiency of existing measures, look at their efficiency in practice and be able to foresee potential implications for their efficiency in light of climate change and land management intensification.

This study presents 18 years of data from a typical Norwegian small CW established in the Skuterud catchment, in Norway. The main objective of this presentation is twofold:

- to look at the impact of hydraulic load, particles, and nutrient loads on CW effectiveness, and
- look at the potential sources and distribution of sediment in the catchment and the constructed wetland.

Results and Conclusions: The water quality monitoring results showed an average of 39 % and 22 % annual removal efficiency for total suspended sediment (TSS) and total phosphorus (TP), respectively. It appears that good CW effectiveness coincides with a combination of high sediment or phosphorus loads to the CW and a stable runoff of low to moderate intensity (Fig. 2).

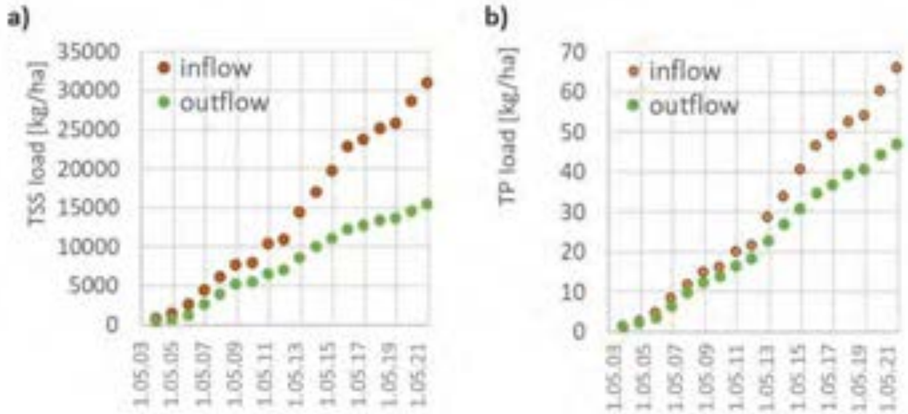

Figure 2: Cumulative (a) sediment loads and (b) phosphorus loads measured at the inlet and outlet of the Skuterud CW (adapted from Krzeminska et al, 2023).

At the seasonal level, the highest TSS and TP removal efficiency is observed in the summer seasons (47% for TSS and 29% for TP), when the sediment and phosphorus load and runoff are at their lowest, and the lowest in autumn (23% for TSS) and in winter (4% for TP) (Fig. 3). The relationship between removal efficiency and loads to the CW is not that straightforward, as other seasonal differences, such as erosion patterns, vegetation development, also become important.

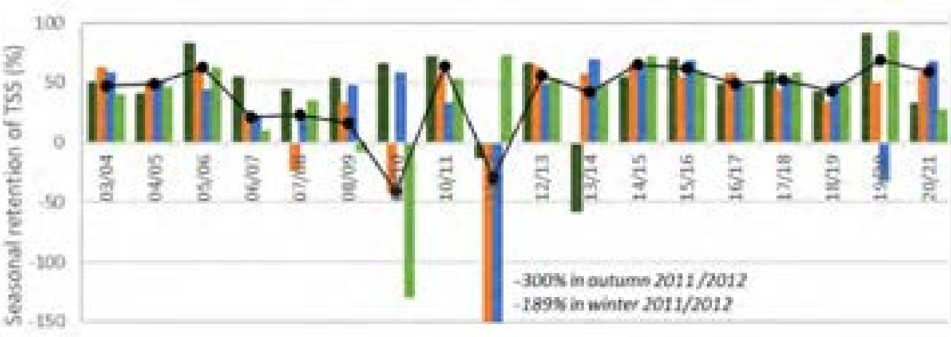

Figure 3: The seasonal TSS removal efficiency of the Skuterud CW (adapted from Krzeminska et al, 2023). NOTE: Black dotes indicates the annual removal efficiency of TSS (added for comparison and demonstrative purposes). Seasons are defined as: summer: May– August; autumn: September–November; winter: December–February and spring: March–April.

Sediment/soil focused analysis of Skuterud CW and the Skuterud catchment gave a good overview of the soil particle distribution and phosphor and nitrogen content in the soil and sediment within Skuterud catchment and Skuterud CW (Fig. 4.)

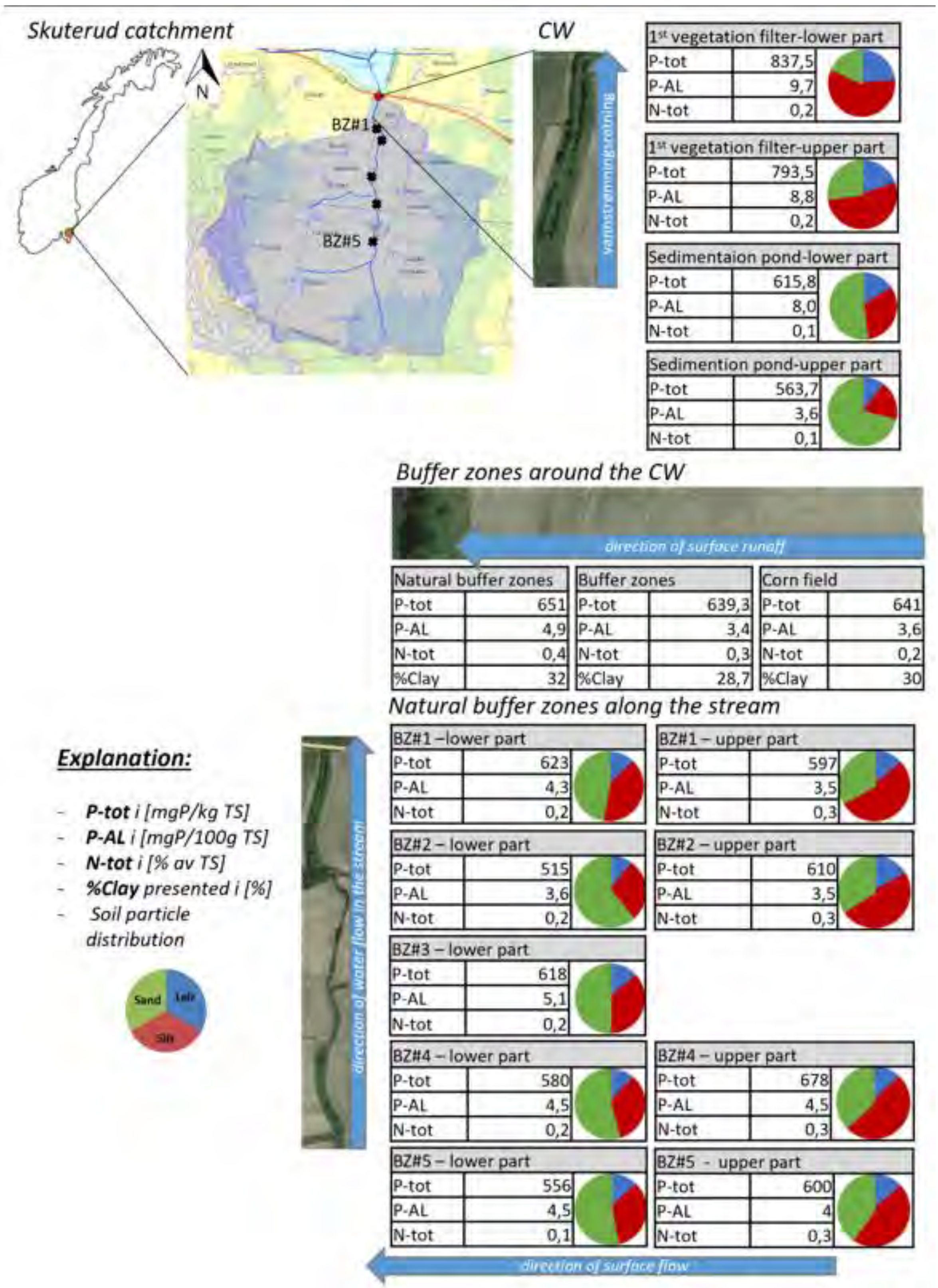

Figure 4. Results of soil/Sediment analysis within Skuterud catchment and Skuterud CW.

The conclusion based on the results presented is that establishing CWs can be a good supplement to best management practice in erosion-prone catchments with sensitive recipients.

References:

Blankenberg, A-G. B., Paruch, A. M., Paruch, L., Deelstra, J., Haarstad, K., 2016. Nutrients Tracking and Removal in Constructed Wetlands Treating Catchment Runoff in Norway. Chapter 2 in: Vymazal J. (eds) Natural and Constructed Wetlands. Springer. Pp 23-40. ISBN: 978-3-319-38926-4. https://link.springer.com/chapter/10.1007/978-3-319-38927-1_2.

Blankenberg, A-G. B., Haarstad, K., Paruch, A. M., 2015. Agricultural Runoff in Norway: The Problem, the Regulations, and the Role of Wetlands. In: Vymazal J. (eds) The Role of Natural and Constructed Wetlands in Nutrient Cycling and Retention on the Landscape. Springer, Cham. https://doi.org/10.1007/978-3-319-08177-9_10

Blankenberg A-G. B., Deelstra J., Øgaard A. F. and Pedersen R. 2013. Phosphorus and sediment retention in a constructed wetland. In M. Bechmann & J. Deelstra (Eds.), Agriculture and environment – Long term monitoring in Norway (pp. 299–314). Trondheim: Akademika Publishing.

Blankenberg, A-G. B., Haarstad, K. and Braskerud, B., 2007. Pesticide retention in an experimental wetland treating non-point source pollution from agriculture runoff. Water Science & Technology, Vol 55, No 3, pp37-44.

Braskerud, B. C. 2001. Sedimentation in small constructed wetlands. Retention of particles, phosphorus and nitrogen in streams from Arable Watersheds. Dr. Scient. Theses 2001:10, Agriculture University of Norway, Ås, Norway

Braskerud, B. C. and Blankenberg A-G. B. 2005. Phosphorus retention in the Lier wetland. Is living water possible in agricultural areas? Jordforsk book nr. 48/05. 145: 126-128. ISSN/ISBN: 82- 7467-537-1.

Carstensen M.V., Molina-Navarro E., Hashemi F., Kronvang B., Bieger K. 2023. Modelling the impact of the Nordic Bioeconomy Pathways and climate change on water quantity and quality in a Danish River Basin, CATENA (222), 106795

Deelstra J., Øygarden L., Blankenberg A-G.B. & Eggestad H. 2011. Climate change and runoff from agricultural catchments in Norway. International Journal of Climate Change Strategies and Management, Vol 3, Iss: 4, pp.345-360

Direktoratsgruppa, 2009. Vanndirektivet: Veileder 01:2009. Klassifisering av miljøtilstand i vann. Økologisk og kjemisk klassifiseringssystem for kystvann, innsjøer og elver i henhold til vannforskriften. 188 pp. (in Norwegian).

Hauge A., Blankenberg A-G. B. and Hanserud O.H. 2008. Evaluering av fangdammer som miljøtiltak i SMIL. Bioforsk Rapport Vol. 3 Nr. 140 2008. (In Norwegian)

Koskiaho J., Ekholm P., Raty M., Riihimäki J. and Puustinen M., 2003. Retaining agricultural nutrients in constructed wetlands - experiences under boreal conditions. Ecological Engineering 20, 89-103.

Øgaard A. F., Kristoffersen A. Ø. and Bechmann M., 2016 – Utredning av forslag til forskriftskrav om tillatt spredemengde av fosfor i jordbruket. NIBIO Rapport Vol 2. Nr. 131 (In Norwegian)

Øygarden L., Deelstra J., Blankenberg A-G.B., Hauge A., Kitterød N.O. and Eggestad H.O., 2011. Runoff and Mitigation Measures in Agricultural Catchments under Climate Change in Norway, in: Kelman, I. (eds) Municipalities Addressing Climate Change. A Case Study of Norway. NOVA Science Publisher, 25-49:150. ISBN: 978-1-61324-716-7.

Rozema E.R., VanderZaag A.C., Wood J.D., Drizo A., Zheng Y., Madani A., Gordon R.J. 2016. Constructed Wetlands for Agricultural Wastewater Treatment in Northeastern North America: A Review. Water 8 (5): 173.

Selvik J.R., Tjomsland T., Borgvang S.A. and Eggestad H.O., 2006. Tilførsler av næringsstoffer til Norges kystområder i 2005, beregnet med tilførselsmodellen TEOTIL2. NIVA-Report 5330 (In Norwegian).

Life cycle assessment of Horizontal Subsurface Flow Constructed Wetlands: The importance of regional characteristics to enhance environmental protection

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Keywords: Nature-based solutions, constructed wetlands, life cycle assessment, environmental impact

ABSTRACT

Introduction

Constructed Wetland (CW) have emerged as a promising ecotechnology for treating wastewater in both rural and urban areas (Sezerino et al. 2015). Similarly to many wastewater treatment technologies, CWs are biological reactors (von Sperling, 2023), i.e., a solution designed to optimize natural processes in an engineering-controlled system, being considered an environmentally sustainable alternative for wastewater treatment (Dotro et al. 2017). CWs enable removing pollutants through the interaction between the porous media, microorganisms, and macrophytes (Matos et al. 2018; Knowles et al. 2011). Several studies have already addressed LCA applied to Constructed Wetlands, but there are still important aspects to be further developed. LCA is a systematic, comprehensive, and standardized process for assessing the potential environmental impacts of a product, practice, or activity using a cradle-to-grave approach (ISO, 2006a). However, the reliability of the results is highly dependent on assumptions and premises defined during the definition of methods, input data and scope. Climate, raw materials, and technologies used are only some of the local characteristics that can highly impact the outcome of LCA. For instance, the electricity mix of a country can not only influence the availability and cost of energy but also affect environmental protection (Souza Henriques et al. 2019). So, the goal of this paper is to present a study addressing to the effect of regional characteristics in the final LCA results for HSFCW.

Material and methods

LCA was conducted following the procedures recommended by the International Standards ISO-14040 (ISO, 2006a) and ISO-14044 (ISO, 2006b). This analysis was performed in four main steps: goal and scope definition, Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA) and interpretation. LCA was carried out using the software SimaPro 9.5®. The goal of this study is to compare the environmental impact assessment of HSFCW installed in different regions around the world. The scope consists in the construction and operation of a HSFCW in different countries. The functional unit adopted was 1 m^3 of wastewater treated. Release to water of organic matter, nitrate and phosphorus was considered in the LCA.

Life Cycle Inventory (LCI) for the inputs related to HSFCW construction was obtained in Beyers et al. (2023), consists in basic construction materials (concrete, pipes, rebars, sand, coatings and bricks) and electricity for the pumping system. Emissions to water and to air were defined based on Fuchs et al. (2011) and Corbella et al. (2017). Flows related to the production and processing of input materials used in the inventory of the constructed wetland were obtained in the database Ecoinvent 3.9®.

Life Cycle Impact Assessment (LCIA) was carried out using ImpactWorld+, mid point approach (Bulle et al. 2019). This methodology was adopted as it provides important updates in terms of the characterization factors approaches as well as regionalization of the analysis. The following impact categories were considered in this study: Climate change, Ecotoxicity, Freshwater acidification, Freshwater eutrophication, Fossil and nuclear energy use, Mineral resources depletion, Ionizing radiation and Land occupation.

For the case study, four countries from different regions were chosen: Brazil, China, France and United States, these countries present distinct characteristics in terms of geographical location, natural resources, climate and electricity mix. Brazil has an electricity mix focused on hydropower, China and USA has a fossil fuel-based system and in France nuclear power is the main source of electricity. Results were interpreted

using tables, statistics (average, standard deviation and relative standard deviation), and graphical representation to support the comparison among the analyzed scenarios in order to verify similarities in pattern results.

Results and discussion

Table 1 presents the environmental impact category results for the HSFCW installed in four countries. It could be observed in different values for basically all the impact categories. Indeed, climate change and mineral resources are the only ones with close results among scenarios, whereas for the other impact categories a very large range of results was obtained, which is supported by the relative standard deviation (RSD), also presented in Table 1. For some of the impact categories, RSD reaches values above 70%, which indicates a strong variability in the results for each scenario.

Table 1: Impact category results for each scenario used in the LCA of the Horizontal Subsurface Flow Constructed Wetland.

Impact category	Unit	Brazil	China	France	US	RSD
Climate change, long term	kg CO2 eq	3,23E+00	3,45E+00	3,19E+00	3,32E+00	4%
Fossil and nuclear energy use	MJ deprived	1,36E+00	3,76E+00	4,33E+00	3,59E+00	40%
Mineral resources use	kg deprived	3,81E-02	4,07E-02	4,16E-02	4,27E-02	5%
Photochemical oxidant formation	kg NMVOC eq	6,80E-04	1,44E-03	4,36E-04	7,71E-04	52%
Freshwater ecotoxicity	CTUe	2,62E+03	4,86E+03	2,65E+03	3,10E+03	32%
Freshwater acidification	kg SO2 eq	1,27E-09	3,71E-09	7,59E-10	1,47E-09	73%
Freshwater eutrophication	kg PO4 eq	5,72E-07	3,10E-07	2,95E-07	2,93E-07	37%
Ionizing radiation	Bq C-14 eq	7,99E+00	9,17E+00	3,05E+01	1,32E+01	69%
Land occupation, biodiversity	m2yr arable	2,77E-02	1,67E-02	2,77E-03	1,63E-02	64%

Figure 1 provides a visual representation of the results where it could be noted that a high variability among scenarios, which indicates how important is regional characteristics to the final results of LCA for HSFCW. In terms of resources, for example, it could be noted that China, US and France have much higher impacts for this impact category than Brazil, which is likely related to the fact that the latter has an electricity mix based on renewables whereas the other are more dependent in fossil fuels (China and US) or nuclear power (France).

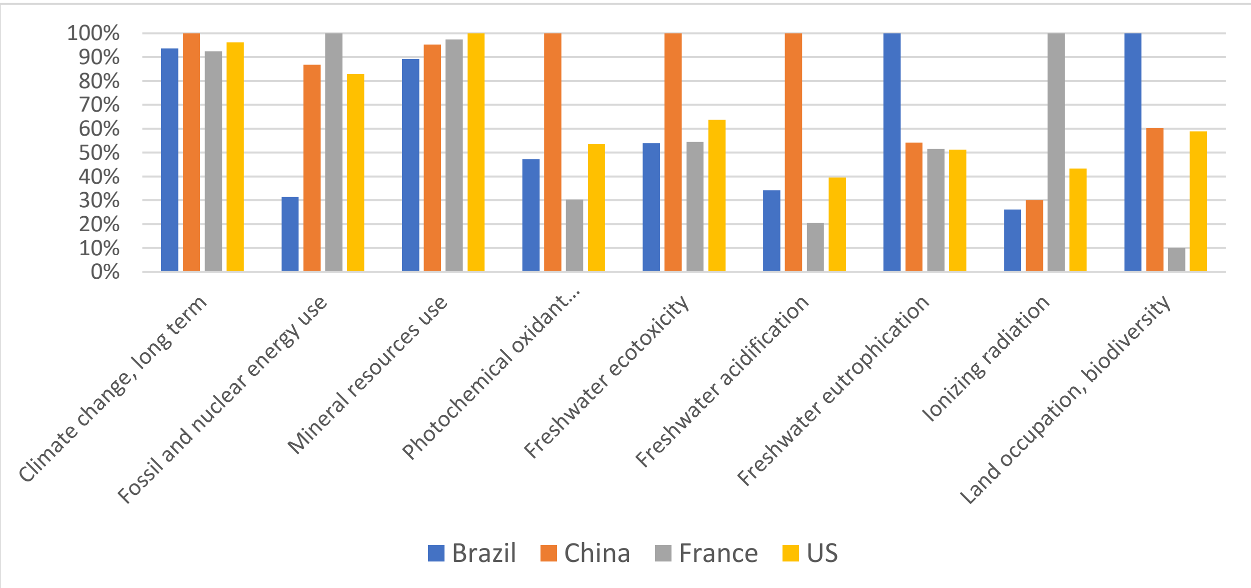

Figure 1: Relative difference among countries of the LCA results of construction and operation for Horizontal Subsurface Flow Constructed Wetland.

On the other hand, Brazil scored as the highest results for land occupation, as hydropower demands lots of space for storage water reservoirs. For ionizing radiation, in turn, the main source of environmental burden that results in the difference observed for France, is related to steel production.

The diamond graph presented in Figure 2 is helpful in better visualizing how different the patterns of impact categories results for the 4 scenarios, with some similarities being China and USA that seem to overlap in Figure 2 for categories related to resources and climate change, but with also several differences for other impact categories. Particularly, it is important to highlight that as HSFCW is a quite simple solution in terms of the infrastructure required, most of the impact comes from the usage stage, mainly the electricity demand due to pumping systems, which makes regional considerations a very important topic, which explains the differences observed mostly linked to electricity mix variations among countries.

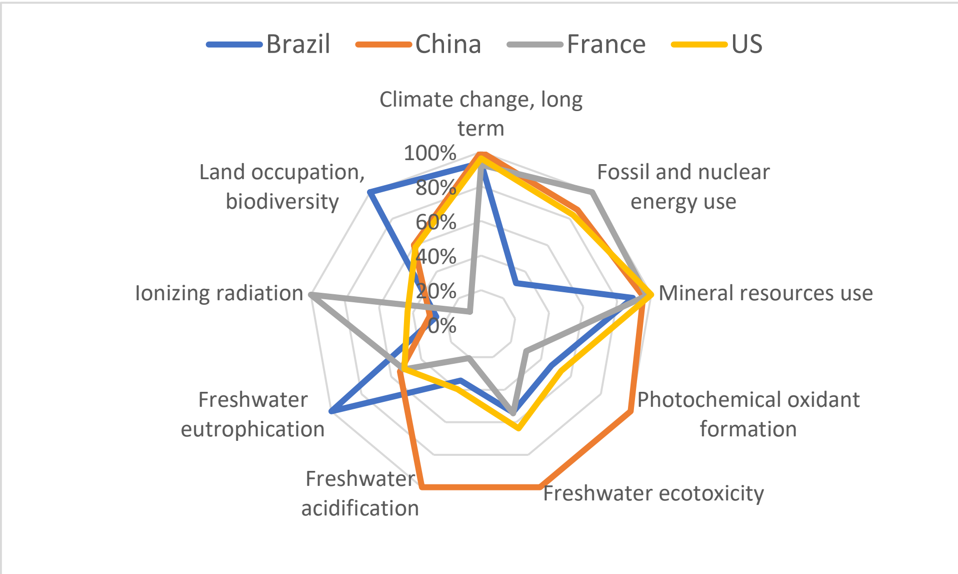

Figure 2: Diamond diagram of the relative results of the 4 scenarios, showing the different patterns from each one.

Provided that LCA results can be a potential source to look for opportunities in terms of environmental impact mitigation. The choice of alternative materials, the substitution of construction procedures, or even the reduction of electricity consumption will be more or less successful to minimize environmental impacts depending on the regional context. It is important to note that, the behavior observed for HSFCW, is likely to occur for other types of CW and even other green solutions, but this hypothesis must be verified in further studies.

This means that an assertive LCA regionalized can support the development of constructed wetlands and other nature-based solutions more aligned with sustainable development goals at a regional level. It is also important to highlight that the differences in regional distinctions observed in this study comprise only the direct changes in inputs and outputs, i.e., differences in mass flows of the processes in each country's inventory. However, even higher differences will probably be found in the results if the LCIA- method incorporates the regionalization of characterization factors.

Conclusions

The results of the comparative LCA assessment reveal significant differences in terms of environmental impacts. Indeed, comparing LCA results among the 4 countries it could be noted that the impact categories have very distinct patterns, which reflect their particularities and specificities. Even if it was considered the same HFCW, the huge difference in terms of the environmental effect of implementing it in different countries points out the importance of regional consideration when assessing nature-based solutions in a way the system can be optimized by focusing on mitigating burdens according to the main issues for the local context. In future studies, the development of regional-specific LCI for CW is recommended to better reflect local aspects.

Therefore, in the light of ecological engineering best practices, the implementation of nature-based solutions like HFCW must be planned integrating regional LCA analysis to enable enhanced environmental protection and overall sustainability of the system. Additionally, the inclusion of more stages in the LCA is also recommended to provide a more holistic overview of the entire life cycle of the system.

References:

Beyers, M., Ravi, R., Devlamynck, R., Meers, E., Jensen, L. S., & Bruun, S. (2023). Constructed wetlands and duckweed ponds as a treatment step in liquid manure handling—A life cycle assessment. Science of the Total Environment, 889, 163956.

Bulle, C., Margni, M., Patouillard, L. et al. IMPACT World+: a globally regionalized life cycle impact assessment method. Int J Life Cycle Assess 24, 1653–1674 (2019).

Corbella, C., Puigagut, J., & Garfí, M. (2017). Life cycle assessment of constructed wetland systems for wastewater treatment coupled with microbial fuel cells. Science of the total environment, 584, 355-362.

Dotro, G., Langergraber, G., Molle, P., Nivala, J., Puigagut, J., Stein, O., & Von Sperling, M. (2017). Biological Wastewater Treatment Series, Volume Seven: Treatment Wetlands, 160p.

Fuchs, V. J., Mihelcic, J. R., & Gierke, J. S. (2011). Life cycle assessment of vertical and horizontal flow constructed wetlands for wastewater treatment considering nitrogen and carbon greenhouse gas emissions. Water research, 45(5), 2073-2081.

ISO. (2006a). International standard 14040. Environmental management-life cycle assessment. Principles and Framework.

ISO. (2006b). International standard 14044. Environmental management life cycle assessment-requirements and guidelines.

Knowles, P., Dotro, G., & O'Hare, P. (2011). Clogging in subsurface-flow treatment wetlands: Occurrence and contributing factors. Ecological Engineering, 37(2), 99–112. https://doi.org/10.1016/j.ecoleng.2010.10.002

Matos, M. P., Dotro, G., Kus, P. M., & O'Hare, P. (2018). Clogging in horizontal subsurface flow constructed wetlands: influencing factors, research methods and remediation techniques. Reviews in Environmental Science and Biotechnology, 17(1), 87–107. https://doi.org/10.1007/s11157-017-9446-3

Sezerino PH, Bento AP, Decezaro ST, Magri ME, Philippi LS (2015) Experiências brasileiras com wetlands construídos aplicados ao tratamento de águas residuárias: parâmetros de projeto para sistemas horizontais. Eng Sanitária e Ambient 20(1):151–158. https://doi.org/10.1590/S1413-41522015020000096615

Souza Henriques, R.; Rezende Saldanha, R.; Goulart Coelho, L.M. An Air Pollutant Emission Analysis of Brazilian Electricity Production Projections and Other Countries. Energies 2019, 12, 2851. https://doi.org/10.3390/en12152851

von Sperling, M., Wallace, S. D., & Nivala, J. (2023). Representing performance of horizontal flow treatment wetlands: The Tanks In Series (TIS) and the Plug Flow with Dispersion (PFD) approaches and their application to design. Science of The Total Environment, 859, 160259.

Session B9: Ecological restoration

The role of natural processes in post mining land reclamation

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Keywords : post mining sites; succession; reclamation

ABSTRACT

Mining typically goes severe environmental damage. This is usually compensated by post mining site reclamation. However, if the post mining side are left unattended natural successional processes can lead to restoration of variable ecosystem. In this contribution we are comparing efficiency of nature processes to restore post mining sides using ten paired chronosequences of reclaimed post mining sites and parallel post mining sites in various environmental situation in Europe, India and North America (Frouz et al., 2008, 2013). When the target is to restore forest ecosystem and sites that has to be restored occur in deciduous forest biome then forest restoration is quite fast. As a matter of fact, rate of canopy closure might be the same for reclaimed sites and for sites which was left for natural succession (Frouz et. al., 2015, Coradini et al., 2022]. Although initial vegetation cover is often observed on reclaimed sides. As concern woody biomass, soil development, water retention and other ecosystem properties, reclaimed sites might be faster in their recovery, however, insert it 30 to 40 years old site a difference between reclaimed and unreclaimed sides disappear. Interestingly none reclined site tends to develop towards natural climax vegetation, even in situation when surrounding ecosystems where highly anthropogenically modified. Basic precondition for successful Forest establishment is avoidance of compaction of overburden. Then overburden is compacted then Forest establishment might be substantially suppressed and grassy ecosystem develops instead. In many cases nitrogen fixing vegetation is used in reclamation. Nitrogen fixers may have higher productivity and my support faster so formation in a very initial stages of ecosystem development. However, this slows down very quickly and in 30 to 40 years old site nitrogen fixers both wood production as well us soil carbon storage in nitrogen fixers is comparable or slower to non-fixers (Frouz et al., 2015).

When we are restoring grassland ecosystem in biome of temperate grasslands, then recognition measures typically lead to much faster ecosystem recovery compared to natural succession.

This survey shows that natural processes my lead to exploration of valuable ecosystem and can be considered as an option for example in locality's when aim of restoration is to restore natural habitat. Moreover, natural processes can bring valuable inspiration for improvement of existing restoration practices.

Acknowledgements

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References:

Coradini, K; Krejcova, J; Frouz, J 2022. Potential of vegetation and woodland cover recovery during primary and secondary succession, a global quantitative review. Land degradation and development 33: 512-526.

Frouz, J., Prach, K., Pižl, V., Háněl, L., Starý, J., Tajovský, K., Materna, J., Balík, V., Kalčík, J., Řehounková, K. 2008. Interactions between soil development, vegetation and soil fauna during spontaneous succession in post mining sites. European Journal of Soil Biology, 44: 109-121.

Frouz, J., Jílková, V., Cajthaml, T., Pižl, V., Tajovský, K., Háněl, L., Burešová, A., Šimáčková, H., Kolaříková, K., Franklin, J., Nawrot, J., Groninger, J.W., Stahl, P.D. 2013. Soil biota in post-mining sites along a climatic gradient in the USA: Simple communities in shortgrass prairie recover faster than complex communities in tallgrass prairie and forest. Soil Biology and Biochemistry, 67: 212-225.

Frouz, J., Dvorščík, P., Vávrová, A., Doušová, O., Kadochová, Š., Matějíček, L. 2015. Development of canopy cover and woody vegetation biomass on reclaimed and unreclaimed post-mining sites. Ecological Engineering, 84: 233-239.

Phytocap soil density specification for optimum plant water use and root growth

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Keywords soil design, soil density, compaction, root length density, plant water use, evapotranspiration landfill cap, phytocap, mine rehabilitation, Australian native plants, soil specification

ABSTRACT

The establishment of urban forests on landfills is an untapped opportunity for urban greening, with the potential to: 1) achieve safe hydraulic containment of wastes through phytocapping; 2) enhance biodiversity and ecological connectivity; and 3) open new possibilities for public amenity. To achieve these multiple benefits requires phytocap designers to be aware of the living nature of these systems, and to create soil conditions that allow the long-term flourishing of phytocap plant communities, while also addressing the critical civil design constraints of waste containment. Ecological engineering expertise crucially needs to be sought throughout the design phase, especially during soil and plant specification.

Soil is the foundation of good phytocap design and economics demand that the soil is readily available at the site or within a practical haulage distance to make the project feasible (Michael et al., 2004). This often means using stockpiled soil, spoils, clean fill, or sourcing soil within a local government area opportunistically from a construction project. Although the use of these 'non-native' soil products appears challenging, many Australian native plants are adapted to nutrient impoverished, skeletal soils, sometimes even affording a competitive advantage under these circumstances ((Prober and Thiele, 2005)Successful soil selection is therefore not a quest for the perfect horticultural medium or topsoil. Rather, it requires a comprehensive understanding of the physical and chemical characteristics of soils at hand, and careful soil-plant matching, to ensure the establishment of the intended plant community.

Once a suitable soil is selected and found to be non-limiting for plant growth, there are two remaining design considerations: the thickness of the soil, and the density at which it is placed. The impact of soil density was investigated in a one year glasshouse study, where a variety of native trees and grasses were grown at relative compaction levels (%RC) ranging from 67% (very soft) to 87% (very hard). This enabled relationships to be derived: between soil density and plant water use; and between soil density and plant root growth; transferable for any soil type. Correlations between the two variables were also considered.

Methods

The selected soil was a spoil from basalt quarrying called 'quarry scalpings' stockpiled in abundance at the landfill site in Wollert, Victoria (37°35'S, 145°2'E). Physical characteristics included: a 2:2:1 gravel:sand:clay particle size distribution commensurate with low total water holding capacity (TAW=30mm/m), and high hydraulic conductivity ($k=10^{-5}$ m/s) (Michael et al., 2007). Standard maximum dry density was 2.02g/cm^3 at an optimum moisture content of 12.7 w/w% and was used to calculate *relative compaction* (%RC). Chemical characteristics included: low organic matter, low N and P, and high pH (8-9). Key plant selection criteria included tolerances of: drought, flooding, alkaline soils, low fertility and free-draining soils (Michael et al., 2005). Biodiversity and indigenous species were also prioritised (Chell et al., 2022) alongside grasses.

The selected plant species, matched to these conditions, were predominantly from the River Red Gum Grassy Woodland and Stony Knoll Grassland/Cliff Escarpment Vegetation plant communities: *Eucalyptus camaldulensis* (River Red Gum –the dominant tree of the indigenous plant community), *Eucalyptus cladocalyx* (Sugar Gum –a hardy non-indigenous wind-break tree), *Acacia mearnsii* (Black wattle – an indigenous nitrogen fixing understory tree), *Allocasuarina verticillata* (Weeping She-oak –an indigenous

nitrogen fixing understory tree), *Microlaena stipoides* (Weeping Grass –an indigenous C3 grassland species), and *Themeda triandra* (Kangaroo Grass –an indigenous C4 grassland species).

The six plant species were grown at four soil density levels (72%, 77%, 82% and 87% RC), replicated five times, in 0.5m tall, 150mm diameter cylinders in a semi-controlled glass house that did not exceed 25ºC, under water-deficit conditions to allow exposure to high soil strengths at each soil density level (Michael et al., 2019). Plant water use was determined by weekly weighing throughout the experiment. Plant root length density was determined at the end of the experiment using image analysis with WinRHIZO.

A series of linear regression models were implemented in R to enable comparison of treatment means and the determination of the relationship between described variables. This analysis served as a key output for deriving soil placement specifications based on root length density and plant water use. ANOVA and Tukey's posthoc tests were used to compare treatment means. Additionally, Pearson correlation was done between plant water use and root length density acknowledging that these measurements occurred over different time periods: mean plant water use was calculated from all plant water use measurements occurring over the trial, whereas root length density was measured as a single event at the end of the trial.

Results

The majority of plant species had the highest water use and root length density at the two intermediate soil density treatments, and the lowest water use and root length density at one of the two extremity (lowest or highest) soil density treatments. The exceptions were *M. stipoides* (Weeping Grass) and *E. cladocalyx* (Sugar Gum) which had the lowest plant water use at the lowest soil density. Additionally, *E. camaldulensis* (River Red Gum) had the highest root length density at the highest soil density and *A. mearnsii* (Black Wattle) had the lowest root length density at an intermediate density treatment.

In terms of magnitude, *T. triandra* (Kangaroo grass) had significantly (more than double) the root length density compared with all other species as well as the highest plant water use. *M. stipoides* (Weeping grass) had the next highest root length density, but this was only significantly different from *A. mearnsii* (Black Wattle). Tree species all had similar root length densities that were not significantly different.

Plant water use and root length density were linearly correlated. The strength of the relationship (Pearson's r) was medium (r=0.45 [95% CI: 0.31-0.64], p<0.00000) but highly statistically significant. Considering grasses and trees as a subset of the correlation, grasses had a large correlation between plant water use and root length density and this was highly significant (r=0.57 [95% CI: 0.30-0.76], p<0.00026) and trees had a small correlation and this was non-significant (r=0.18, [95% CI: -0.11-0.44], p=0.2245), although the trend (gradient) for both subsets were similar. Considering the gradient of the linear trendlines in Figure 1, plant water use is expected to be on average 20-25% of plant root length density *irrespective of soil density*.

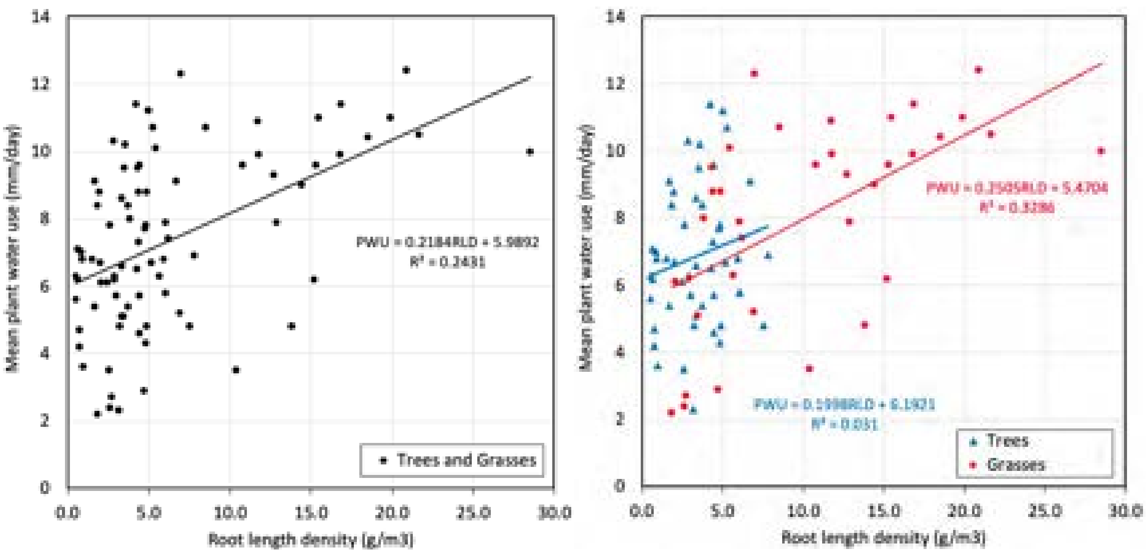

Figure 1 Linear trend between mean plant water use and total root length density for six Australian native plants. The left graph considers trees and grasses together; and the right graph considers trees and grasses separately. R^2 values are not the same as Pearson r reported in the text.

Considering the *impact of soil density* on plant water use and root length density, the relationships derived from the linear regression in R have a parabolic shape with an optimum at moderate density (76.5% RC for PWU and 79.5% RC for RLD), decreasing more steeply as soil density becomes lower or higher. For plant water use, the parabola is gentler and less symmetrical; compared with root length density, where the parabola is steeper and more symmetrical; within the range of densities studied (Figure 2, left). When the relationships are combined, the resulting interpolated graph has an optimum at 78.6% RC and incorporates the raw treatment means within confidence limits for the upper three density treatments (77%, 82% and 87% RC); diverging outside the confidence limits for the lowest (72% RC) density treatment (Figure 2, right).

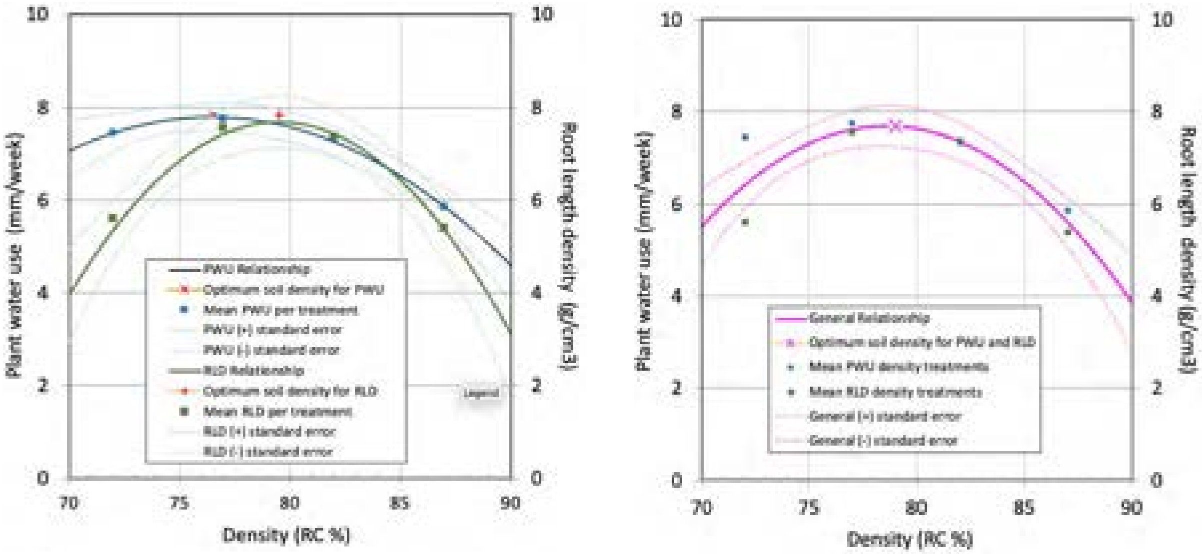

Figure 2 General relationship between soil density (% Relative Compaction) and two variables: plant water use and root length density. Left: shows both variables. Right: shows an average of both variables.

Discussion

Plant water use was selected for its ability to tell us how much water each plant species used under similar watering conditions, when only soil density was varied. This gave us an indication of both hydrological plant performance, as well as the interaction between plant performance and the varying water storage capacity and water deficit conditions unique to each soil density treatment (Forster et al., 2022)Plant root length density was selected as a secondary variable for its ability to indicate how a critical aspect of the plant's underground morphology (the roots) responded to soil density, with implications for the exploratory capacity of the plant and its capacity to forage for water within the soil profile. Further, the use of relative compaction (%RC) as a measure for soil density allowed us to compare soil density levels irrespective of soil texture so that the results of this study can be meaningfully translated across soil types.

Although the plant species varied in their response to soil density, it was possible to create meaningful general models for the six varying plant types, that incorporated this variability within reasonable confidence limits. This is because, for the most part, plant species responded favourably to moderate soil density levels, and less favourably to less moderate (either low or high) soil densities. This was true for both plant water use and root length density with optimum performance occurring at soil densities of 76.5 and 79.5% RC respectively. This concurs with other relative compaction (RC) studies where 77% RC was found to be optimum using a coal overburden substrate (Kim et al., 2022).

In terms of range, keeping soil density between 70-83% RC for plant water use and 75-84% RC for root length density, will optimise these parameters within a 10% range. Small adjustments outside of this leads performance to decline markedly. The patterns of response are similar for plant water use and root length density above 75%, however diverge below 75% RC. For example, at 70-75% RC there is unlikely to be any negative impact on plant water use, although root length density may be affected.

There are limitations to making correlations between plant water use (measured periodically as plants were growing) and root length density (measured at a single event at the end of the monitoring period). Despite these differences in time scale, there is a highly significant medium strength linear relationship between the two variables. Although the trend was similar, the correlation was stronger for grasses than for trees when considered as a subset, with the correlation for trees not significant when considered alone. This makes sense given the different characteristic of tree roots compared with grass roots which are more uniform in morphology and thickness. Therefore, if considering root length density as a proxy for potential plant water use, it is more reliable for grasses.

Implications for practice

Considering multiple perspectives of plant performance on an ecologically engineered phytocap cap, it is clear that soil needs to be placed at soil densities lower than 85% RC to optimise plant water use and root length density. It is acknowledged that the soil density ranges that can be achieved with full-scale earth-moving equipment depend on the technique used and the susceptibility of the selected soil to compaction. If achievement of these lower densities is challenging with conventional cap placement equipment, a soil placement trial is recommended to trial alternative construction sequencing, techniques, and equipment until there is confidence that the specifications can be achieved. No traffic options may need to be considered. Within a soil density range of 75-83% RC both plant water use and root length density are optimised within 10% of optimum performance. Where possible placement of phytocaps at these density levels are recommended. However, given the choice between over-compaction (>85% RC) and under-compaction (<70% RC), it is better to tend towards lower soil densities with appropriate adjustment of estimated soil volumes and thickness during design to allow for self-weight settlement.

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References

Chell, S., Tomson, N., Kim, T.D.H., Michael, R.N., 2022. Performance of native succulents, forbs, and grasses on an extensive green roof over four years in subtropical Australia. *Urban Forestry & Urban Greening*. 74:1-11. https://doi.org/10.1016/j.ufug.2022.127631

Forster, M.A., Kim, T.D.H., Kunz, S., Abuseif, M., Chulliparambil, V.R., Srichandra, J., Michael, R.N., 2022. Phenology and canopy conductance limit the accuracy of 20 evapotranspiration models in predicting transpiration. *Agricultural and forest meteorology*. 315https://doi.org/10.1016/j.agrformet.2022.108824

Kim, T.D.H., Yu, B., Srichandra, J., Low-Choy, S., Michael, R.N., 2022. Water flux and biomass production of native plants at different substrate compactions for landfill phytocaps in Southeast Queensland, Australia. *Ecological Engineering*. 183:106745. https://doi.org/10.1016/j.ecoleng.2022.106745

Michael, R., Yuen, S., Baker, A., Laidlaw, S., Bateman, S., 2007. A Sustainable Approach for Hydraulic Control of Landfills Using Quarry Scalpings and Native Plants. *Australian Journal of Multi-disciplinary Engineering*. 5:39-47. http://doi.org/10.1080/14488388.2007.11464755

Michael, R.N., Yu, B., Wintle, B.A., Doronila, I.A., Yuen, S.T.S., 2019. The effect of substrate compaction on plant water use and the implications for phytocap design specifications. *Ecological Engineering*. 127:195-203. https://doi.org/10.1016/j.ecoleng.2018.11.023

Michael, R.N., Yuen, S.T.S., Baker, A.J.M., Bateman, C.S., 2005. Utilisation of Mine Wastes in Plant Based Alternative Cover Trials. Proceedings Sardinia 2005: Tenth International Waste Manangement and Landfill Symposium. Cagliari, Italy: CISA, Environmental Sanitary Engineering Centre, 2005.
Michael, R.N., Yuen, S.T.S., Bateman, S., Baker, A.J.M., 2004. Evapotranspiration Landfill Cover at Wollert, Victoria. Sustainable Waste Management Conference. Melbourne. WMAA.
Prober, S.M., Thiele, K.R., 2005. Restoring Australia's temperate grasslands and grassy woodlands: integrating function and diversity. *Ecological Management & Restoration*. 6:16-27.

Organic amendments-based technosols for the restoration of Mediterranean habitats and soil-carbon sequestration

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Keywords: Nature-based solutions, circular economy, waste valorization, ecological restoration, mine land restoration, soil stabilization.

ABSTRACT

Forest restoration is part of the EU 2030 forest strategy that foresees ensuring forest restoration and reinforcing sustainable forest management for climate adaptation and forest resilience. Moreover, the NextGenerationEU program tries to achieve a good state of ecosystem conservation through ecological restoration when necessary, and to reverse the loss of biodiversity, guaranteeing a sustainable use of natural resources and the preservation and improvement of its ecosystem services. The restoration of heavily degraded landscapes (polluted soils, areas affected by wildfires, road embankments, extractive activities, dump fills) should be a priority in this restoration plans. In this context, Technosol construction in slope restoration works is a practice that allows reusing former soils, recovering mineral wastes and recycling organic residues, contributing to the green and circular economy, while improving the results of revegetation. The use of organic amendments, which can be organic wastes (sewage sludge, digestate of biowaste, manure, biostabilized, etc.) or commercial products (compost, vermicompost, humic organic amendments, etc.), allows accelerating the biological colonization of inert substrates. The appropriate combination of these mineral and organic materials, mixed and placed to emulate the horizons of natural reference soils, allows the construction of Technosols, to cover the surface of geotechnically-stable slopes. In the medium term (5-10 years) these Technosols, built with adequate doses of organic amendment (a maximum of 50 Mg/ha, dry weight), allow the recruitment of native species, increasing the plant diversity of the slopes and its ecological value. In the long term (>20 years), these Technosols manage to sequester organic carbon significantly and effectively, up to nine times more than without the use of amendments. The short, medium and long-term results of various cases of success (and failure) of the use of organic amendments in soil rehabilitation are presented (Solé et al, In press; Carabassa et al., 2018; Carabassa et al., 2019). In turn, a series of criteria are proposed for the selection and use of organic amendments in soil rehabilitation tasks (Carabassa et al., In press; ARC, 2022; Carabassa et al., 2018; Alcañiz et al., 2009), giving specific guidelines for the different residues and organic products usually available in European countries, while establishing the requirements of quality of mineral substrates in the context of their use for Technosols construction.

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References:

ARC (2022) Aplicació d'esmenes orgàniques en la restauració de sòls degradats. Fitxes tècniques. https://residus.gencat.cat/ca/ambits_dactuacio/tipus_de_residu/residus_organics/restauracio_sols/fitxes_tecniques/

Alcañiz, J.M., O. Ortiz and V. Carabassa. (2009) Utilización de lodos de depuradora en restauración. Manual de aplicación en actividades extractivas y terrenos marginales. Barcelona: Agència Catalana de l'Aigua, Generalitat de Catalunya.

Carabassa, V., Domene, X., Díaz, E., Alcañiz, J.M. (2019). Mid-term effects on ecosystem services of quarry restoration with Technosols under Mediterranean conditions: 10-year impacts on soil organic carbon and vegetation development. Restoration Ecology; https://doi.org/10.1111/rec.13072

Carabassa V, Ortiz O, Alcañiz JM. (2018) Sewage sludge as an organic amendment for quarry restoration: Effects on soil and vegetation. Land Degrad Dev. 2018;1–7. https://doi.org/10.1002/ldr.3071

CARABASSA, Vicenç; POUS, Meri; BATLLÓ, Glòria, GONZÀLEZ, Robert; DOMENE, Xavier; VIDAL, Andrea; ALCAÑIZ, Josep Maria (In press) Utilització d'esmenes orgàniques en rehabilitación de sòls. Agència de Residus de Catalunya: Barcelona.

Solé P., Ferrer D., Raya I., Pous M., Gonzàlez R., Alcañiz J.M., Carabassa V. (In press) Physical and chemical properties of limestone quarry Technosols used for the restoration of Mediterranean habitats

Ecological engineering enhances ecological restoration in Chinese desertified lands

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Keywords : Sand-binding vegetation, desertification control, ecological restoration, arid desert regions, water balance, soil habitat

ABSTRACT
China is one of most severely affected countries by desertification. The total area of desertification affected land is 2.6 million km^2, accounting for 79.06% of total area of arid, semi-arid and dry sub-humid areas and 27.3% of the total national land territory. They are mainly distributed in the northwest, the north central plain and the west part of the northeast China. 400 million people are impacted by desertification and annual direct economic loss from desertification is about US$6.5 billion. In order to combating desertification, a series of ecological engineering have been used to prevent and control desertification since 1950s, including a variety of engineering measures and revegetation. Over the past 70 years, China has made great achievements in desertification control and most of degraded lands have restored. The application of ecological engineering based on sanddune fixation by revegetation has played a great role. The gist of which is to use the sand-barrier (straw-checkboard) to immobilize the mobile dunes, then plant the seedling of indigenous xerophytic shrubs, forming artificial vegetation protect systems. However, the density of shrub seedlings and cover of artificial vegetation were determined by soil water content of local sanddune. Long-term monitoring indicated this approach greatly increased the accumulation and deposition of dustfall on the fixation dune surface, enhancing the colonization and survival of cyanobacteria, desert green algae, and lichens, as well as mosses, forming biological soil crusts (BSC). The development of BSC on fixed dune surface improved soil properties, increasing the proportion of clay and silt in soil texture, forming soil aggregate, increasing the accumulation of C、N、P and other important elements in topsoil, promoting the soil formation on dune surface; increasing the soil water availability in topsoil; providing a well habitat for establishment and survival of annual and perennial plants, as well as soil arthropod. In regions with precipitation between 100 and 200 mm such as in the Tengger Desert, if don not consider groundwater, the artificial shrub communities with a simple structure and higher cover (30%-45%) have been replaced by stable vegetation communities composited by shrubs (10% of cover), herbaceous (35%) and BSC nonvascular plants (>50%) after 70 years since sand-binding vegetation has been established. Meanwhile, a new water balance has been maintained between vegetation and soil (soil water kept 1.5%~2.5%). The soil organic carbon and total nitrogen stocks in 17-, 52- and 60-year-old artificial shrublands were 1.2, 2.7, 2.8 and 1.2, 2.3, 2.5 times greater than those in mobile sand dunes, respectively. The recovery in soil properties and forming stable sand-binding vegetation were proposed to be important indexes to evaluate the success of restoration practice in desertified lands.

SIGNIFICANCE OF SOIL TYPE AND APPLIED FERTILIZATION ON THE CONTENT AND UPTAKE OF MACROELEMENTS WITH SUNFLOWER BIOMASS IN POT EXPERIMENTS

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Keywords: soils; fertilization norms; N, P, K, Si, Ca, Mg uptake; sunflower.

ABSTRACT

The study aim is to evaluate the effect of different soil types – Alluvial-meadow and Leached smolnitsa, different norms and combinations of nitrogen, phosphorus, potassium, and silicon fertilizers on the content and uptake of some main macro elements with medium-early hybrid Sunflower (Helianthus annuus L.) - Sumiko HTS. In Alluvial-meadow soil as a result of the one-way variance analysis, the data obtained for the amount of plant biomass on the 67th day established the leading role of the nitrogen rate of 200 mg per pot and silicon at 800 mg per pot. The largest biomass was reported in variant V4 ($N_{200}P_0K_{140}Si_{800}$) from the beginning of the experiment and the best plant development was in variants V4 ($N_{200}P_0K_{140}Si_{800}$) and V12 ($N_{300}P_{80}K_{210}Si_{400}$) on day 67. So these combinations of fertilizers are optimal for plant nutrition. At the same time in Haplic vertisol, the leading role of nitrogen fertilization with high norms of 200, 300, and 400 mg/pot and silicon 800 mg/pot was established as a result of the experiment carried out in a vegetation house and from the single-factor dispersion analysis of the values for the amount of biomass of sunflower plants on the 67th day, (the proven difference between variants is at a high confidence level $P \leq 0.001$). To sum up, the leading role of nitrogen is evident but in order to improve agricultural production and soil fertility, and reducing environmental impact there is a need to optimize the nutrient regime of plants.

Introduction

Sunflower (*Helianthus annuus* L) is a major oilseed crop in Bulgaria. New hybrids and promising sunflower lines, distinguished by a number of their characteristics and physiological requirements, are constantly entering the practice. In terms of nutrient supply, hybrids with the highest requirements are followed by varieties with high oil content, while those with low oil content are the least demanding.

The nutrient requirements for yield formation depend both on the specific soil and climatic conditions of the area and on several other factors. The importance of fertilization is paramount (Ahmad I., et al., 2017; Zichuan Li, et al., 2018). Sunflower responds well to nitrogen fertilization - excess nitrogen lowers oil content and lowers plant resistance to disease. Appropriately balanced phosphorus and potassium fertilization increase yield and oil content (Nenova L., Mitova V., 2018). Silicon (Si) is not classified as an essential element for plants, but numerous studies have described its beneficial effects under various soil and climatic conditions, including low levels of plant-available forms of silicon. The application of Si shows the potential to increase the availability of nutrients in the rhizosphere and their uptake by plants (Pavlovic J., et al., 2021). Determination of optimal nutrient regime for crops requires establishing the export and consumption of nutrients to form a unit of production, and their balance in the soil for different soil conditions.

The study aim is to evaluate the effect of different soil types – Alluvial-meadow and Leached smolnitsa, different norms and combinations of nitrogen, phosphorus, potassium, and silicon fertilizers on the content and uptake of some main macro elements with medium-early hybrid Sunflower (Helianthus annuus L.) - Sumiko HTS.

Materials and methods

In the spring of 2021, a vegetation fertilizer trial with a test crop of an early to mid-early hybrid of sunflower (Helianthus annuus L.) - Sumiko HTS of Sinjenta was set up and established. The initial soils are Alluvial-meadow soil and Leached smolnitza supplied by the experimental field in Tsalapitsa, Plovdiv region, and in Bozhurishte, Sofia. According to the classification of soils in Bulgaria (Koinov V., 1987), they are defined as Eutric Fluvisol – Fleu and Haplic vertisols (FAO, 2015). The first is characterized by a neutral soil reaction in the plowing horizon (pHH2O 7.4), with a low content of total (0. 052%) and mineral nitrogen (11.52 mg N/kg soil). The soil has a low supply of mobile phosphorus (8.09 mg P2O5 /100 g soil) and available potassium (14.35 mg K2O /100 g soil). Haplic vertisol is characterized by a close to neutral soil reaction in the plowed layer (pHH2O - 6,4, pHKCl - 5.6), with a high content of total (0,217%) and mineral nitrogen (40,32 mg N/kg soil). The soil has a low supply of mobile phosphorus (1,92 мg P2O5/100 g soil) and better available potassium content (30,86 mg K2O /100 g soil).

Before sowing the seeds, fertilizers with different amounts of active substances in mg/pot were added to the experimental containers of 3 kg capacity, as presented in Table 1. Five sunflower seeds were sown, leaving 3 plants in each pot at a later stage. On the 67-th day of vegetation in the budding phase, the plants were harvested, weighed, and prepared for chemical analysis. The content (% a. d.w.) of macronutrients N, P, K, Si, Ca, and Mg in sunflower plant biomass was determined by acid digestion and ICP readings (5800 ICP - OES system - Agilent). The export of the tested elements with the plant production was determined.

The experiment included 16 fertilization treatments in 3 replications. It is a multifactorial scheme with four factors varied at 5 levels (Sadovski A., 2020). Table 1 shows the experimental design and the imported amounts of the active substance of the macroelements used in mg/pot.

Table 1. Scheme of a pot experiment and quantities of active substance in mg/pot:

V1. $N_0P_0K_0Si_0$ - Control	V5. $N_{200}P_{320}K_{140}Si_{800}$	V9. $N_{200}P_{160}K_{140}Si_{2000}$	V13. $N_{300}P_{80}K_{70}Si_{1200}$
V2. $N_0P_{160}K_{140}Si_{800}$	V6. $N_{200}P_{160}K_0Si_{800}$	V10. $N_{200}P_{160}K_{140}Si_{800}$	V14. $N_{100}P_{240}K_{210}Si_{400}$
V3. $N_{400}P_{160}K_{140}Si_{800}$	V7. $N_{200}P_{160}K_{280}Si_{800}$	V11. $N_{300}P_{240}K_{70}Si_{400}$	V15. $N_{100}P_{240}K_{70}Si_{1200}$
V4. $N_{200}P_0K_{140}Si_{800}$	V8. $N_{200}P_{160}K_{140}Si_0$	V12. $N_{300}P_{80}K_{210}Si_{400}$	V16. $N_{100}P_{80}K_{210}Si_{1200}$

The following soil analyses were performed before and after the vegetation experiments: pH - potentiometric in H_2O and KCl (Arinushkina, 1962); total and mineral nitrogen content - Bremner and Kinney method (Bremner, 1965a; Bremner, 1965b); mobile forms of phosphorus and potassium (P_2O_5 и K_2O) - by the acetate-lactate method (Ivanov, 1986); organic carbon (humus) content - according to Turin's method (Kononova, 1963). Statistical analysis of the obtained results was done with Statgraphics statistical product (ANOVA).

Results and Discussion

From the dry weight data of sunflower plants presented in Tables **2** and **4** it is clearly seen that the lowest weight is obtained in the control variant in both soil types - 9.25 and 10.97 g/pot for alluvial meadow soil and Leached Smolnitza. It is the highest in V4. $N_{200}P_0K_{140}Si_{800}$ -16.71g and V12. $N_{300}P_{80}K_{210}Si_{400}$ -16.34g of alluvial meadow soil and in V5. $N_{200}P_{320}K_{140}Si_{800}$ - 46,20g и V12. $N_{300}P_{80}K_{210}Si_{400}$ – 44.97g respectively of leached smolnitza. It can be seen that these are the variants with higher nitrogen norms. At the same time, on the alluvial-meadow soil, higher values were achieved in V8 ($N_{200}P_{160}K_{140}Si_0$), V12 ($N_{300}P_{80}K_{210}Si_{400}$) and V13 ($N_{300}P_{80}K_{70}Si_{1200}$), and in the B3 variant with the highest nitrogen rate (400 mg/pot) the weight of the plants was significantly lower than that with N_{300} norm. Therefore, on both soils the effect of N300 norm is maximum, and has favorable effect. The further increase in nitrogen norm has a negative effect, especially on alluvial-meadow soil.

Table 2. Dry mater (g/pot) and uptake by sunflower (кg/da) from Tsalapitsa

Variant	Dry matter	N	P	К	Si	Ca	Mg
1	9.25	6.33	1.64	9.89	0.79	0.92	2.35
2	13.32	24.40	6.92	30.17	4.42	23.41	8.90
3	15.20	33.38	7.25	29.00	4.17	27.63	6.43

4	16.71	37.44	5.26	35.93	5.19	30.52	9.92
5	10.03	19.41	5.69	19.04	3.17	18.23	5.33
6	13.16	36.83	6.87	23.45	4.43	25.70	8.88
7	12.76	25.96	6.09	29.07	3.66	21.94	6.89
8	16.11	46.69	8.26	34.51	5.83	33.35	11.02
9	15.29	34.54	6.74	25.59	13.43	26.42	6.88
10	12.26	31.11	5.74	22.06	4.10	23.17	7.83
11	13.44	29.76	7.26	22.98	5.66	26.25	8.71
12	16.34	36.16	5.73	26.76	6.82	24.40	5.88
13	13.94	37.51	6.40	24.84	11.74	23.71	5.52
14	13.77	27.14	6.07	28.01	3.62	20.70	6.82
15	16.05	29.46	7.94	29.17	11.91	25.56	7.94
16	14.69	29.62	5.55	29.88	1.45	23.40	6.21

Table 3. Dry mater (g/pot) and uptake by sunflower (кg/da) from Bozhurishte

Variant	Dry matter	N	P	K	Si	Ca	Mg
1	10.97	5.50	0.86	6.45	0.40	5.86	1.18
2	21.09	6.33	1.46	11.83	1.90	10.82	2.15
3	41.66	24.12	3.62	21.00	8.80	24.50	8.62
4	28.87	24.60	2.08	18.54	3.00	16.72	5.20
5	46.20	28.42	3.74	14.83	3.20	17.33	5.96
6	41.61	33.08	3.62	20.10	6.40	23.09	7.49
7	38.34	23.23	2.99	20.70	3.00	1.84	5.75
8	34.47	18.92	2.69	16.44	2.70	16.65	6.82
9	37.12	18.82	2.67	17.04	11.50	18.93	6.68
10	40.17	19.28	3.13	18.08	3.50	21.21	7.35
11	42.99	37.01	3.87	19.60	3.90	22.70	9.93
12	44.97	31.43	3.10	25.77	4.30	25.90	8.50
13	40.62	27.42	2.32	18.28	3.20	19.74	8.17
14	29.97	15.91	2.43	18.07	3.30	16.09	4.68
15	42.04	18.54	3.53	21.94	3.50	21.06	6.43
16	31.65	17.38	1.99	14.24	2.00	11.49	3.51

Conclusion

In Alluvial-meadow soil as a result of the one-way variance analysis, the data obtained for the amount of plant biomass on the 67th day established the leading role of the nitrogen rate of 200 mg per pot and silicon at 800 mg per pot. The largest biomass was reported in variant B4 ($N_{200}P_0K_{140}Si_{800}$) from the beginning of the experiment and the best plant development was in variants B4 ($N_{200}P_0K_{140}Si_{800}$) and B12 ($N_{300}P_{80}K_{210}Si_{400}$) on day 67. So these combinations of fertilizers are optimal for plant nutrition. At the same time in Haplic vertisol, the leading role of nitrogen fertilization with high norms of 200, 300, and 400 mg/pot and silicon 800 mg/pot was established as a result of the experiment carried out in a vegetation house and from the single-factor dispersion analysis of the values for the amount of biomass of sunflower plants on the 67th day, (the proven difference between variants is at a high confidence level $P \leq 0.001$).

Nitrogen is a major nutrient that determines the growth of oilseed crops and increases the amount of protein and yield. Biomass accumulation in sunflower is related to nutrient uptake throughout the growing season (Hassan F. & Kaleem S., 2014).

It is established that the changes in the macroelements uptake significantly follow changes in the quantities of the relevant elements in dry biomass in the variants of the experiment. With an increase in fertilization norms, not only the content of N, P, and Si is increased, but also the uptakes with sunflower biomass. This trend is expressed to a lesser extent with potassium.

There is only a very slight tendency to increase the phosphorus content in the plants with increasing fertilizer rate in Haplic vertisol. Changes in exports of the macroelements examined have been found to follow changes in the quantities of the relevant elements in dry biomass in the variants of the experiment.

Si content increases from 0.0111% in the control variant to 0.0976% in the variant with the highest Si rate. This tendency is similar for both soil types. The combinations of norms and fertilizers used in the experiment do not establish a direct relationship between increasing the accumulation of Si in plants with increasing the imported Si level.

The calcium content is high and ranges from 1.21 to 1.96% but it is significantly higher in the fertilized variants in Haplic vertisol. The content of Ca is very low - 0.13% in the control variant of Alluvial meadow soil but is significantly higher in the fertilizer variants from 1.66 to 2.30% and it cannot be said categorically that higher fertilization rates lead to higher accumulation of Ca in sunflower plants.

The change in the content of Mg varies similarly in both soil types, respectively 0.33 and 0.36% in the control, and in the fertilized variants it is between 0.44 and 0.76% (in Alluvial meadow soil) and between 0.37 and 0.77% (in Haplic vertisol). Applied fertilization has a significantly lower effect on the accumulation of Mg in sunflower plants.

To sum up, the leading role of nitrogen is evident but in order to improve agricultural production and soil fertility, and reducing environmental impact there is a need to optimize the nutrient regime of plants.

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References:

Ahmad, I., Jadoon, S. A., Said, A., Adnan, M., Mohammad, F., & Munsif, F. (2017). Response of sunflower varieties to NPK fertilization. Pure and Applied Biology (PAB), 6(1), 272-277.

Bremner, J.M. (1965a). Organic Nitrogen in Soils, Agron. J., 10, 93-149.

Bremner, J.M. (1965b). Inorganic forms of Nitrogen. In: C.A. Black et al., /Eds./. Methods of Soil Analyses. Part 2: Chemical and Microbiological Properties. № 9, Agronomy. American Society of Agronomy Inc. Madison, Wisconsin, USA, pp. 1179-1237.

Hassan, F.U., Kaleem, S. (2014). Influence of seasonal disparity on NPK uptake in sunflower. The Journal of Animal & Plant Sciences, 24(1), 190-196.

Ivanov, P. (1986). New Acetate-lactate Method for Determination of Available Forms of P and K in Soil. Soil Science and Agrochemistry, 19 (4), 88-98.

Koinov, V. (1987). Correlation between the soils of Bulgaria and the soils distinguished by the major soil classification systems in the world. Soil Science, Agrochemistry and Plant Protection, 22(5), pp. 5-13 (Bg)

Kononova, M.M. (1963). Soil organic matter. Its nature, properties and methods of study. M., AN SSSR, 314 p.

Nenova, L., Mitova, V. (2018). Content and uptake of macroelements with the production of cabbage. Soil Science Agrochemistry and Ecology, 52, 3, 34-42. (Bg)

Pavlovic, J., Kostic, L., Bosnic, P., Kirkby, E.A., Nikolic, M. (2021). Interactions of silicon with essential and beneficial elements in plants. Frontiers in Plant Science, 12, 1224.

Sadovski, A. (2020). An Introduction to Mathematical Agronomy: Theoretical and Experimental bases. LAP Lambert Academic Publishing. ISBN 978-620-2-51889-5, 284 pp.

Session B10: NBS for climate change adaptation

CARDIMED - Climate Adaptation and Resilience Demonstrated In the MEDiterranean region

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Keywords: Nature based Solutions, Climate Adaptation, Resilience, Mediterranean

ABSTRACT

Over the last decade, NBS and related measures such as green-blue infrastructure and water-sensitive urban design have emerged as win-win solutions for Climate Resilience that contribute to both climate adaptation and mitigation, while providing a wide range of co-benefits for societal challenges. The European Union (EU) has driven the development of NBS, highlighting their value as an effective systemic solution in key policy documents such as the *European Green Deal*, *the New EU Climate Adaptation Strategy*, *EU Biodiversity Strategy for 2030* and the *Urban Agenda for the EU*. More recently, the COVID-19 and the increasingly evident climate change impacts have stressed the urgent need for the large-scale development and mainstreaming of NBS [1], as they can simultaneously support human health, reduce disaster risk, mitigate heat waves, improve surface water quality and promote sustainability of natural resources. However, to achieve this paradigm shift, and mainstream NBS, critical barriers must be overcome [2]. The main barriers stem from uncertainties related to (i) planning for climate adaptation at local-regional scales, (ii) the interdependencies of NBS design, cost, and performance with local environmental conditions, (iii) the lack of knowledge of policy-makers, communities and professionals about NBS and (iv) the receptivity of NBS as viable alternatives of, or complementary upgrade for grey infrastructure. Although NBS have proved their technological readiness, and continue their innovative evolution, the institutional readiness at local and regional levels remains at low degrees, hindering the mainstreaming of NBS and allowing the business-as-usual pathway in infrastructure development to dominate [3].

What is urgently needed, is widespread, on-the-ground evidence for NBS and their effectiveness in tackling climate change. Data and actions must be co-produced with local communities and stakeholders, who will embrace nature as the pathway to resilience and scale them up to the regional level [4]. In order to maximize the co-benefits of implemented NBS the provision of holistic solutions addressing the Water-Energy-Food-Ecosystems (WEFE) Nexus in cities, industrial, rural, and natural areas, are crucial. WEFE Nexus approaches are gaining momentum as the security challenge of water, energy, food and ecosystems has become a major concern worldwide. NBS are considered as solutions that can help tackling this challenge, but most of the currently available assessment methodologies and tools for NBS do not follow a nexus approach, but rather on the evaluation of single or few benefits provided by NBS. The impact as well as the synergies and trade-offs of NBS to the WEFE Nexus are not thoroughly investigated.

To this end, **CARDIMED** aims to enhance Climate Resilience in the Mediterranean by mainstreaming Nature-based Solutions in systemic transformation. The project, a part of the EU mission on Adaptation to Climate Change, will demonstrate 47 different types of Nature-based Solutions through 83 interventions across 10 regions and 20 locations. Participating communities will establish the CARDIMED Resilience Alliance, which will function as the vehicle for expanding the network via upscaling the existing sites and adding new ones. The project expects to have 28 regions and 70 communities in the network by 2030, create 8000 jobs in the NBS sector, and mobilize over 450 M€ in climate investment.

To realise this vision, CARDIMED recognises the importance of integrating innovation across multiple disciplines, structuring the project on four pillars (Figure 1). The first pillar includes digital technologies and EO (satellite, in-situ, citizen) integrated datasets for better knowledge gathering and understanding of climate resilience. Pillar 1 provides the foundation for an augmented interaction of different stakeholders with NBS solutions and their impacts, also leveraging multiple data streams for insightful information in local and regional scales. The second pillar focuses on governance structures, stakeholder engagement, open science, and financing, particularly through the

proliferation of Nature-Based Enterprises. Pillar 2 provides the interface for stakeholder collaboration and commitment to capacity building. The third pillar includes high level data integration to provide adopters with the capacity of designing and implementing circular solutions through the WEFE Nexus to address climate resilience challenges. The final pillar focuses on implementing NBS for large-scale replacement of grey infrastructure. Every pillar provides indispensable innovations for the systemic transformations necessary to build climate resilience.

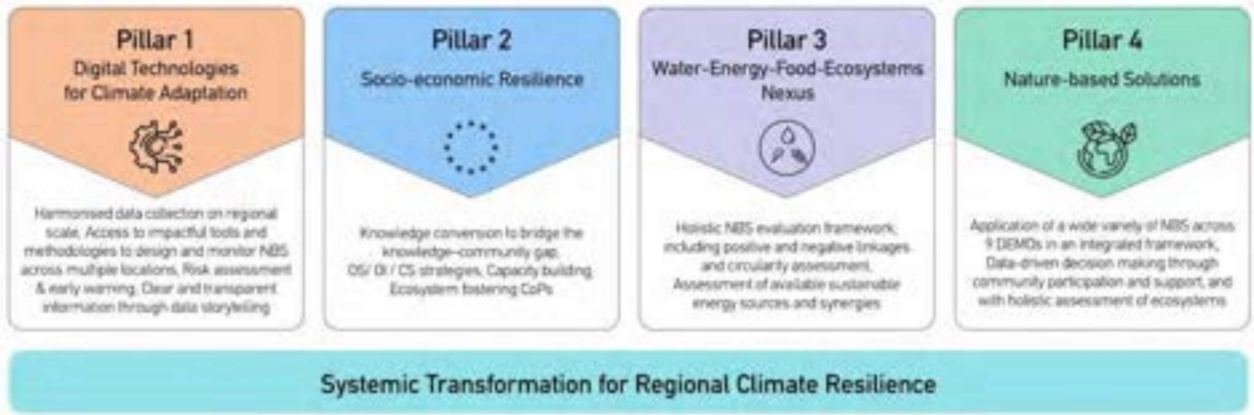

Figure 22 Four CARDIMED pillars for systemic transformation for regional climate resilience.

While individual solutions for each pillar exist, the biggest challenge and transformative potential are to holistically connect these solutions and make them functioning at system level, which is ultimately the main objective of the project. To achieve this objective CADIMED will implement, test, and demonstrate nature-based and circular solutions fostering digital, social, and systemic transformation by delivering the network of 9 clusters of Demonstrators (DEMOs). The NBS DEMOs will provide critical tailor-made solutions in dealing with the locally identified regional climate change multi-risks and will support the region in building Climate Resilience through nature-based climate change adaptation and mitigation measures at the local and regional levels. 9 NBS DEMOs (Greece (2), Italy (2), France, Spain, Portugal, Turkey, Cyprus) will be demonstrated across the Mediterranean biogeographical region, comprising 20 locations, 28 communities and 47 NBS in total, covering the whole spectrum of urban, peri-urban, rural areas (Figure 2).

Figure 23 Spectrum of scenarios addressed across the urban-rural continuum.

Figure 3 shows the CARDIMED DEMOs, their locations, the NBS implemented in each case and the replication regions. Those will focus on:

DEMO1 Non-conventional water loops on North-South Aegean islands, Greece: Cluster of 3 sites featuring a combination of constructed wetlands, subsurface water harvesting and innovative water/wastewater treatment and reuse technologies, nutrient recycling and traditional water management techniques to deal with water scarcity.

DEMO2 Industrial symbiosis through smart water management in Central Greece: Introduction of NBS in industrial DEMO level improving water circularity supported by digital twins.

DEMO3 Decarbonization of agricultural practices and combating agricultural pollution in Sardinia, Italy: NBS will be employed to decarbonize the agricultural cultivation and livestock sector and decontaminate the agricultural runoffs, combined with renewable energy systems, achieve efficient water distribution of reclaimed water for irrigation.

DEMO4 Raingardens and living walls in Sicily, Italy: DEMO4 features two communities in Catania and Ferla and will address urban flood risk reduction, water scarcity, and upgrading grey infrastructure with NBS. In Ferla, an NBS green wall for greywater treatment and reuse will be implemented in the local school, reducing the potable water currently wasted for toilet flushing. In Catania a SuDS will be developed to combat the floods issues.

DEMO5 Micro-forests and unsealed soils in Provence-Alpes-Côte d'Azur region, France: DEMO5 will focus on renaturation and unsealing of impermeable urban areas, and creation of green public space for human health and quality of life of citizens in 2 parts of Aix-Marseille. By planting trees on currently sealed urban areas, reducing heat island effects and risk for floods. Citizens will benefit from improved air quality, shade, and edible fruits.

DEMO6 Forest management and heatwave resilience in Aragón, Spain: DEMO6 will introduce sustainable forest management, encouraging local species to restore natural vigour of the forest. In addition, primary schools and public spaces in Zaragoza will be re-naturalized with green infrastructure.

DEMO7 Cultural landscape restoration in Alentejo, Portugal: DEMO7 is focused on the ecological restoration of woodlands and riverside vegetation at a regional level, as well as control invasive species. Focus on the creation of partnerships with public and private entities to carry out conservation, recovery, restoration, and enhancement projects in sensitive areas that are rich in endogenous heritage.

DEMO8 Indigenous production landscapes in Izmir, Turkey: DEMO8 will implement NBS for ecological and shallow water marine environment habitat restoration and creation, to deal with long-term climate resilience to sea-level rise, ecological degradation, and salinity intrusion.

DEMO9 Gardens of the future in the heart of Nicosia city, Cyprus: DEMO9 will introduce circular NBS for urban greening, hydroponic food production, phytoplankton water treatment and public space irrigation.

The selected NBS will cover the 3 NBS types [5], namely Type 1: Improved use or protection of natural ecosystems, Type 2: NBS to improve managed ecosystem sustainability or function, and Type 3: Design and management of newly created ecosystems. CARDIMED will expand the scope of NBS interventions in the MED area by demonstrating and enhancing NBS with innovations and characteristics, such as:

NBS typologies and engineering level: The variety of contexts will allow the demonstration of NBS of all types and categories ranging from soft management actions to innovative, highly engineered solutions, to be implemented in natural areas with exquisite biodiversity up to complex multi-stakeholder urban environments such as public spaces. Demonstrated NBS will focus on the restoration of ecosystems of regional and international importance that suffer from climate change induced degradation and support the establishment of ecological corridors. The DEMOs of CARDIMED will facilitate the dynamics of natural processes and build on the multiple co-benefits that NBS can offer due to the ecosystem services they provide.

NBS for bioeconomy: Circular Economy principles and practices will be embedded in the demonstrated solutions. This includes industrial symbiosis among different industries where NBS will become the driver for this water recovery and reuse, valorisation of municipal, rural and industrial process by-products, composting, fertigation to support agriculture, towards more resilient cities, agriculture and forestry sectors.

NBS for the WEFE Nexus: The NBS implementations address the WEFE Nexus by providing tested solutions that lead to climate resilience by combining climate adaptation and mitigation benefits, through innovative circular economy approaches. Recent academic literature has explored the application of the WEFE Nexus approach even in urban areas, and has identified challenges related to technical, sustainability and governance issues [6].

Innovative NBS materials: Biochar will be employed as a novel filling material to tackle industrial pollution for the removal of heavy metals to recycle water for industrial purposes. Coke material that is accumulated with bacteria to promote biological treatment will be used for sewage treatment.

NBS for agricultural drainage water treatment: The NBS will be optimised for agricultural runoff treatment, also in the conditions of variable hydraulic and pollutant loading rates. Moreover, nutrient recovery and its circulation will be assessed through NBS biomass and substrate use as a soil amendment.

Intensive Constructed Wetlands: Solutions that require much lower space requirements compared to conventional CWs due to the application of air (aerated CWs) and the flow of electrons (electroactive CWs), thus facilitating the application within the urban context where land availability is limited.

NBS for flood protection: Full scale SuDS in real applications are rare in the MED, with limited references in literature. Within CARDIMED we will verify the possibility to have an effective multidisciplinary development, able to accomplish the main benefit of pluvial flooding attenuation, with side benefits of first flush treatment from high traffic road (water quality), keeping a pleasant aesthetic (amenity) and supporting urban biodiversity.

NBS for digital innovation: Collection of a wealth of data to quantify and communicate to a wide range of communities the benefits and positive impacts of NBS to climate resilience. Creation of knowledge basis for upgrading critical infrastructure and combining it with a wide array of tested and demonstrated NBS.

Acknowledgements

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References:

[1] Moglia, Frantzeskaki, et al. (2021). Accelerating a green recovery of cities: Lessons from a scoping review and a proposal for mission-oriented recovery towards post-pandemic urban resilience. Developments in the Built Environment, 7, 100052.

[2] Viti et al. (2022). Knowledge gaps and future research needs for assessing the non-market benefits of Nature-Based Solutions and Nature-Based Solution-like strategies. Science of the Total Environment, 156636.

[3] Van Cauwenbergh, et al. (2022). Beyond TRL–Understanding institutional readiness for implementation of nature-based solutions. Environmental Science & Policy, 127, 293-302.

[4] Fastenrath, S., Bush, J., & Coenen, L. (2020). Scaling-up nature-based solutions. Lessons from the Living Melbourne strategy. Geoforum, 116, 63-72

[5] Eggermont et al. (2015) Nature-based Solutions: New Influence for Environmental Management and Research in Europe GAIA - Ecological Perspectives on Science and Society 24(4):243 – 248

[6] Carvalho et al. (2022). Nature-based solutions addressing the water-energy-food nexus: Review of theoretical concepts and urban case studies. Journal of Cleaner Production, 130652.

Development of a climate change adaptation plan for the Jordan Valley based on WEFE nexus analysis: The EcoFuture project

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Keywords: desertification, Mediterranean region, social priorities, Nature-based Solutions, Causal Loop diagrams, Living Labs

ABSTRACT

The Mediterranean region is considered a "Hot Spot" susceptible to the threat of climate change. Many regions are prone to desertification, reduced water and change of rainfall pattern, loss of fertile soil, and degradation of the ecological services provided. Using the Jordan Valley as a test case, the overall objective of the new EcoFuture project, funded by the PRIMA programme (under GA number 2243), is to develop a climate-change adaptation plan oriented towards improving the socio-economic welfare for people in the Mediterranean region based on Water-Energy-Food-Ecosystem (WEFE) nexus methodologies. The project builds on the research and innovation capacities of partners and local stakeholders in order to: 1) Propose a climate change adaptation plan for the Jordan Valley region, based on existing and emerging technologies, taking into account the social and economic priorities of the three involved jurisdictions (Jordan, Israel and Palestine); 2) Use techno-economic models to optimise the sustainable efficiency (economic, society and environment) performance of the Plan; 3) Use socio-economic models to assess and recommend policies in the WEFE context to improve the welfare of people in the region; 4) Perform tests in three demonstration sites in the Jordan Valley, one in each country, in order to validate the inputs to the various models; 5) Propose methodologies to extend the applicability of the results of the Jordan Valley to other regions and to other Mediterranean countries; 6) Build synergies across sectors to investigate interlinkages across the nexus; 7) Implement capacity building and training programs in response to project findings.

EcoFuture is developing WEFE Nexus best-practice recommendations for resource management in the Jordan Valley; an area that is indicative of typical arid and hyper-arid zones of the MENA (Middle East/North Africa) region in terms of water scarcity, water accounting, water use efficiency, and public health, to maximise the socio-economic impact. It seeks to identify and quantify the adaptation challenges to water, food and energy security and to the environment, and finally, will propose an adaptation plan based on state-of-the-art technologies and adaptation solutions, including centralised and decentralised wastewater treatment, smart agriculture and precise irrigation, solar desalination, renewable energy. Through engaging communication activities, EcoFuture will improve the awareness of citizens, stakeholders and policymakers towards a sustainable future. The project accounts for the social priorities of the three involved countries, and uses innovative techno-economic models to assess policies and actions for improving the welfare of the people in the region. Tests are performed at existing WEFE demonstration sites in order to validate the inputs to the various models, and thus propose best available methodologies to extend the applicability of results to other Mediterranean countries.

The principle behind this WEFE concept is to provide Security of Supply (SoS) for the major resources (water, energy, food and ecosystems) in the most effective way. However, SoS is a subjective matter and differs from country to country, and from region to region. In the Jordan Valley region three countries are involved, each with significant differences in their conditions and approach to SoS. One way to overcome this obstacle is to define a set of agreed questions related to the SoS definition, questions that have quantitative, well-defined answers. The answers can provide the constraints and/or the boundary conditions to the models that are used. The questions have to follow the full chain-of-supply of any required product and address linkages between the WEFE sectors. The building of the set of agreed questions and the collection of the answers in the three countries requires intimate discussions and agreement between all the stakeholders in all countries. Stakeholders are engaged by creating Living Labs in each country and the local perception on the WEFE Nexus will be identified using mind maps and Causal Loop Diagrams. The results will then be integrated into acceptable alternatives for Nature Based Solutions that will optimize the WEFE Nexus and improve the well-being of the citizens in the Jordan Valley with poposed adaptation and mitigations measures in response to climate change.

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A glimpse into the euPOLIS multi-dimensional Indicator System for Site Screening & NBS Assessment

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Keywords: Nature-Based Solutions (NBS), Indicator Framework, NBS Selection, NBS Evaluation, Urban Upscaling

ABSTRACT

1. Introduction

Evaluating the impact of Nature-Based Solutions (NBS) via appropriate indicators and metrics has attracted, in the past few years, significant interest. In response to this, the European Commission has recently published a handbook that aims to serve as a guide towards the evaluation of NBS impacts (EC, 2021) based on current available knowledge and state-of-art technologies and practices. The evaluation process, which involves the development and estimation of pertinent metrics, is crucial across the different NBS implementation stages, i.e., from the selection and design of effective NBS interventions to the NBS efficiency evaluation and potential improvement of the deployed systems. Within this context and as part of the work that was carried out for the euPOLIS project, an integrated indicator-based methodological framework is proposed herein for assessing the multi-dimensional aspects and impacts associated with the implementation of NBS in urban environments. The proposed framework employs different types of indicators with distinct functions and purposes and aims at providing structured guidance to practitioners and urban planners throughout all the different NBS analysis, deployment, and evaluation stages.

2. euPOLIS Indicator NBS Assessment Framework

A multi-dimensional indicator-based methodology is proposed herein, focusing on aspects related to the NBS intervention effect on Public Health (PH) and Well-Being (WB), which include direct PH & WB impacts, as well as indirect ones, such as socio-cultural, environmental, and economic impacts. Since this indicator methodology aims to cover different phases associated with an NBS implementation project, it introduces two sets of indicators: (1) Contextual Indicators (CIs) that are used for the NBS planning phase, and (2) Evaluation Indicators (EIs) that are used for monitoring during the NBS deployment and exploitation phase. Both sets of indicators are developed within five (5) different categories: (a) PH & WB, (b) social, (c) business/economic, (d) environmental, and (e) urban development, as well as various identified associated Challenges and Themes, which represent the main topics and physical/social processes relevant to NBS implementation.

Figure 1 presents the overall euPOLIS NBS Assessment Framework and how this has been conceptualised for the different analysis stages. CIs are utilised during the planning phase to provide an initial site screening and site characterisation by facilitating an initial baseline assessment founded on readily available data. The baseline assessment process is anticipated to assist in gaining a better understanding of the site, the crucial issues as well as their severity and consequently the urban site's needs (Step 1). This leads to the next step (Step 2), that involves the identification of potential NBS interventions that could target the site-specific issues and needs using relevant urban planning processes; in the case of euPOLIS this is accomplished by means of the Goal Driven Planning Matrix (GDPM) methodology (Bozovic et al., 2017). The initially identified NBS interventions are then evaluated through i) the NBS preliminary selection tool (Baki et al., 2023) (Step 3) and potentially ii) more in-depth through applicable simulation and assessment methods, so as to eventually select and design the final NBS to be implemented at an urban site of interest (Step 4). Following the final selection of NBS, a tailor-made list of EIs is produced based on the expected impacts of the implemented NBS (Step 5). The aforementioned list will be used for the performance evaluation of the implemented NBS (Step 7) following the NBS and monitoring system deployment (Step 6).

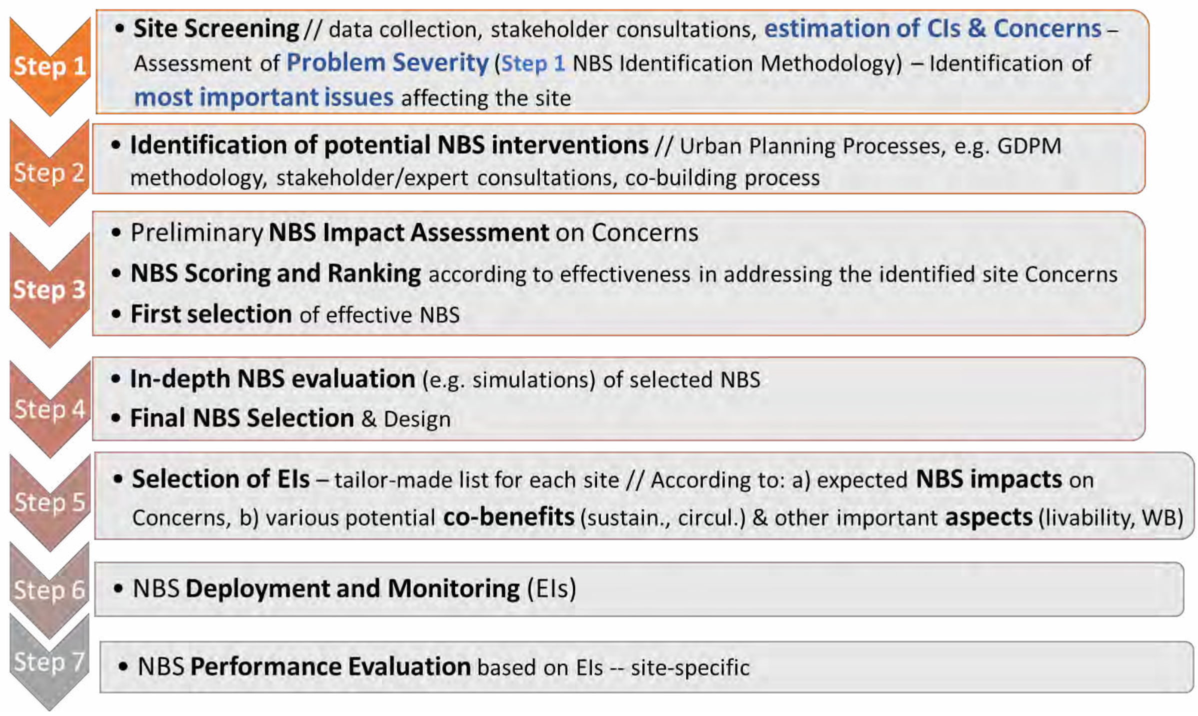

Figure 1: Conceptualisation of the euPOLIS NBS Assessment Framework

3. CIs and Site Screening Process

The main purpose of the CIs is to facilitate a coherent quantitative site screening analysis at the beginning of an urban-upscaling project, via utilising readily available data that does not require the existence of an on-site monitoring scheme. In particular, the evaluation of CIs is based on readily available data and sources, including national and international databases, local agencies and authorities, existing reports, questionnaires, site visits, etc. The data reflect the temporal and spatial resolution level that is most appropriate (and available) for the urban site of interest.

Even though many different CIs have been identified, only a core group of these indicators is considered critical for the site screening process, since these indicators address site specific issues that could potentially be mitigated through the implementation of NBS (e.g., flooding, extreme heat, community engagement, etc.). Specifically, the evaluation of this concise list of CIs, monitors the site performance across 28 persistent Concerns associated with the aforementioned five categories, to eventually assist practitioners in identifying the more pressing problems that are being faced at a particular urban site, which could, either directly or indirectly, be mitigated by implementing specific NBS. Some of the Concerns are estimated through more than one CIs, eventually forming the so-called composite CIs. For each CI specific thresholds have been set in order to classify and score the site performance that is measured by each one of them in a standardised manner. This site screening analysis is utilised for the initial ranking and selection of candidate NBS interventions according to their anticipated effectiveness in addressing high-severity concerns in a particular site of interest, according to the NBS preliminary selection methodology and online tool presented by Baki et al. (2023).

4. EIs and NBS Performance Assessment

In total 80 EIs have been defined, within the five aforementioned euPOLIS categories, as suitable to assess the different direct and indirect impacts that NBS could have on PH & WB. EIs' function is to assess the performance and effectiveness of the implemented NBS through comparing the indicator values prior to and after the implementation of the NBS at the site of interest. The data needed to estimate the EIs at these two stages are collected either via i) monitoring through environmental sensors, questionnaires, wearables monitoring PH & WB parameters and using people as a source of data; ii) modelling/simulations using appropriate models; or iii) targeted data collection (Randelović et al., 2023) (Figure 2). This process results in a multi-dimensional impact assessment of the implemented NBS.

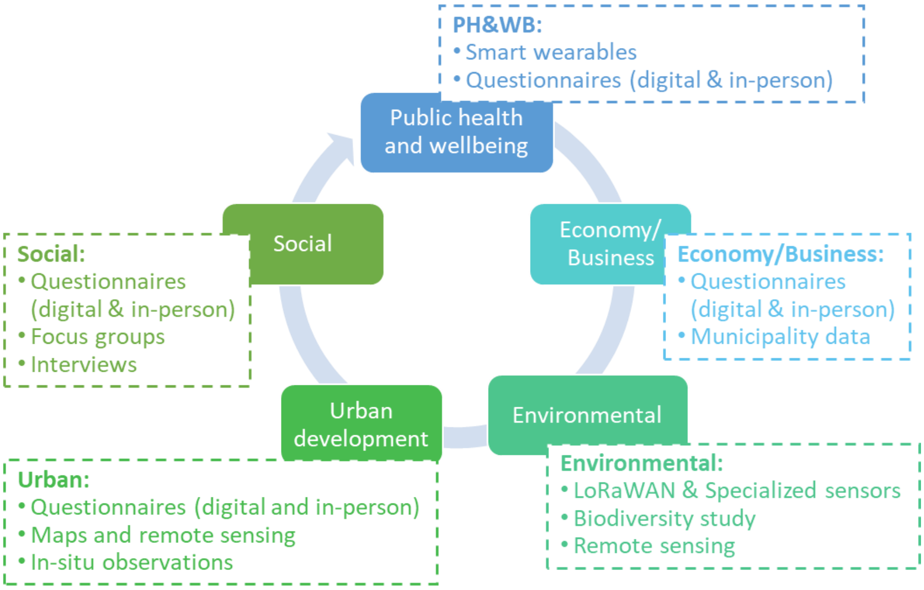

Figure 2: EI estimation means across the five indicator categories

Contrary to the list of CIs that is common across the different urban sites, aiming to provide, to the extent possible, a standardised screening process, the list of EIs is tailor-made for each site. Hence, the selected EIs should serve the need of quantifying the expected impacts of the implemented NBS, or, to put it otherwise, to evaluate how effectively an NBS that was selected to upgrade a certain urban site addresses the main site Concerns for the remediation of which it has been selected. Practitioners are also recommended to select EIs that evaluate the co-benefits resulting from NBS implementation, even though these impacts might not be linked to high severity Concerns. Additionally, there might be a need to assess other important aspects, such as "Sustainability", "Circularity", "Livability" and "Wellbeing", and in this case it is recommended to select corresponding EIs from the developed indicator clusters.

5. Conclusions & Future work

The site screening methodology, that involves the evaluation of the core CIs and related Concerns, has been applied in all euPOLIS Front-Runner (FR) cities demonstration sites. Figure 3 presents indicative results for Akti Dilaveri, one of the demonstration sites in the euPOLIS FR city of Piraeus, Greece. This process has significantly assisted in identifying the most pressing issues in each demo site, as well as the most appropriate/efficient NBS interventions following a scoring and ranking process. It has also facilitated a comparative overview and has highlighted the peculiarities and uniqueness of each city/area.

In terms of the EIs, the related indicator methodology has not been validated with field data since the monitoring systems and NBS have not yet been deployed in the demonstration sites. Once the necessary data is obtained, the EI methodology, as well as the indicator definitions and estimation methods are going to be critically assessed and adjustments and modifications are going to be applied where necessary.

Figure 3: Indicative site screening results for the euPOLIS demonstration site of Akti Dilaveri, in the city of Piraeus

Overall, the proposed indicator-based methodological framework is considered innovative in view that it attempts to monitor multiple societal challenges that could simultaneously be addressed by the implemented NBS and consequently provide evidence for their multi-functional role with particular emphasis on citizens' PH & WB. Furthermore, this framework provides the methodological foundation upon which all the activities related to NBS implementation can be based on, including quantitative demo site screening and needs assessment, NBS and indicator (EIs) selection, and NBS assessment, thus offering an integrated assessment methodology and providing guidance to practitioners on NBS analysis and deployment in a structured manner from start to finish.

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References:

Baki, S., Kazantzi, A., and Makropoulos, C., 2023. NBS efficiency-informed urban upscaling methodology: the euPOLIS approach, EGU General Assembly 2023, Vienna, Austria, 24–28 Apr 2023, EGU23-17125, https://doi.org/10.5194/egusphere-egu23-17125.

European Commission, 2021. Evaluating the impact of nature-based solutions: A handbook for practitioners. European Commission, Directorate-General for Research and Innovation, European Union. https://doi.org/10.2777/244577.

Randelović, A., Figueras, A., Seidelin, F., Briggs, L., and Stanić, F., 2023. Nature-based Solutions (NBS) at work and monitoring their performance – the innovative research case of the EU-funded project euPOLIS, EGU General Assembly 2023, Vienna, Austria, 24–28 Apr 2023, EGU23-17063, https://doi.org/10.5194/egusphere-egu23-17063.

Bozovic, R., Maksimovic, C., Mijic, A., Smith, K.M., Suter, I., and van Reeuwijk, M., 2017. Blue Green Solutions: A Systems Approach to Sustainable, Resilient and Cost-Efficient Urban Development, Technical report, Imperial College London, doi: 10.13140/RG.2.2.30628.07046.

The water reuse potential of nature-based solutions in response to the increased water scarcity risks imposed by climate change

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Keywords: Nature based solutions; Water reuse; Natural processes; Climate change, adaptation and resilience; Water scarcity; Rainwater; Sustainability; Circular economy

ABSTRACT

The adding pressures of climate change on the natural resources are particularly obvious in water stressed areas and are introducing additional challenges related to water management, water availability and conservation of the natural resources. Adaptation to the new climatic and socio-economic conditions requires innovative solutions with minimal impact on the already stressed resources and ecosystems. Following the principles of ecological engineering, the nature-based solutions on rainwater harvesting and management, the 'so-called' Sustainable Urban Drainage Systems, have a high potential for water reuse, an option that can be considered to offer a new water resource of particular significance for the water scarce regions. The current paper is, therefore, aiming to present the water reuse element and the ways to achieve it through recognising the nature-based solutions as means to ensure water security, reduce the risks of climate change and water scarcity and provide new options based on the principles of sustainability and circular economy.

Introduction

Water scarcity is overall defined as the lack of water, however, it has different levels and meanings, such as: a. the lack of availability due to physical scarcity, occurring when an area does not have sufficient natural water resources to meet the needs of the population and the economic activities of the area; b. the lack of access to safe and reliable drinking water, which may be caused either due to limited water infrastructure, or distance from water sources, or even socio-economic constraints; c. the failure to ensure regular supply due to lack of adequate infrastructure, such as water supply and water treatment networks, that may lack the capacity to accommodate the needs of the area in a consistent manner. Different levels of water availability are defined as: a. water stress, the state of annual per capita water supply of below 1700 m^3; b. water shortage is when the annual per capita water supply is between 1000 and 1700 m^3; c. water scarcity levels are met for less than 1000 m^3 per capita supply; d. while for less than 500 m3 per capita supply we consider the area to suffer from absolute water scarcity and drought (UN Water, 2020). Drought is a multifaceted phenomenon affected by several parameters, such as the a. Climatic conditions and changes in the precipitation rates adding on the uneven distribution of water resources; b. Geographical characteristics, eg. latitude of a region, mountains, islands; c. the geomorphological relief e.g. the length of the coastline, high altitudes.

Under the increased pressure imposed by climate change, that is expected to increase the challenges related to water security and sanitation, countries such as Ethiopia, India, Kenya, Nigeria and Peru are expected to have exhausted their existing fresh water resources by 2025, fact that necessitates the sustainable use of water resources and the increase of the water reuse potential to the maximum (UNESCO-UN Water, 2012). According to the latest UN reporting on the progress towards the SDGs (2021), more than 733 million people currently reside in areas heavily affected by water stress and 700 million people are expected to be displaced by 2030 due to water scarcity (UN, 2022). Furthermore, seven EU countries already seem to suffer from water shortages (World Resources Institute - JRC 2019; Eurostat, 2023). In Europe, although existing infrastructure is expected to prevent extended water shortages, water scarcity will impact the different sectors of economic activity and the society, and will cause further loss of forest areas, drought, flooding and erosion, impacts on agricultural production, on tourist activities, on operations and industrial facilities.

Where do we currently stand?

The White Paper on 'Innovative Solutions to Cope with Water Scarcity', issued by EIT Body of Experts (2021), identifies a list of practices and economic measures to address water scarcity and promote sustainable water use at reduced environmental costs. The solutions and measures to be implemented should be tailored to the specifics of regions and needs.

- Full Cost Recovery: Expand on the 'polluter pays principle' to introduce the concepts of financial, environmental and resource cost, that is to include the capital investment and maintenance cost, as well as the current cost for the use of the resource, as well as the depletion or deterioration cost of the resource for future use (Tsani *et al,* 2021).

- Promotion of Nature-based Solutions for rainwater management providing sustainable water management and enhancement of natural water ecosystems and resource restoration (Apostolaki, Jefferies, 2009; Apostolaki et al, 2006).

- Water Reuse, either through the use of nature-based solutions, such as infiltration trenches, porous pavements, ponds, wetlands, or through collection and treatment of wastewater, aerobic treatment, and water disinfection. The use of alternative water sources, such as reclaimed wastewater or harvested runoff, can be an economically viable alternative for water supply in certain applications.

- Water Conservation through awareness raising efforts and education. Economic incentives or taxation may contribute to more efficient use of water resources.

- Efficient monitoring and control of water use and losses through smart options of water metering and consumption and the use of smart irrigation techniques.

- Reduction of Food Waste to reduce the use of water waste associated with food production. Economic incentives and awareness can be used to encourage water savings throughout the food chain, as well as innovative and smart agricultural practices

The portrayed nature-based solutions for rainwater management in the White Paper, provide numerous benefits in the context of climate change by reducing greenhouse gas emissions and enhancing carbon sequestration, as well as on the adaptation and increase of resilience. They have the ability to ease the impacts of climate change, such as flooding, landslides, to regulate temperatures, heatwaves, and droughts by regulating water flow and improving the soil-water-holding capacity, while providing natural cooling effects. These benefits, in turn, contribute to the reduction of the urban heat island effects, creating more livable and sustainable cities. In addition, they also provide the conditions for attracting biodiversity and enhancing ecosystems and urban landscapes to resemble natural ones, while they achieve significant levels of pollutant removal with direct benefits to the receiving water bodies (Apostolaki et al, 2006).

One significant benefit of nature-based solutions for rainwater is the ability to harvest, store and treat rainwater to a degree that enable the reuse. The water reuse potential varies depending on the type of the solution and it may be enhanced with the appropriate design. The water to be stored, either underground or aboveground, may be used primarily for secondary uses, thus irrigation, industrial water needs, fire-fighting, urban space cleaning, or even to support the drinking water demand if it undergoes additional treatment and disinfection. The identified solutions with the highest storage potential for water reuse include the: Vegetated Infiltration Beds – Infiltration trenches, Rain Gardens, Swales, Detention Basins, Retention Ponds and Constructed Wetlands (Morales-Torres, 2015).

Water collection and reuse is not a new invention, it follows traditional practices which are, however, re-invented and enhanced to allow for maximization of the stored amount and also to include the treatment element. In water scarce areas, traditionally, rainwater was collected and stored in tanks and used without any treatment. In many cases the water stored could develop microorganisms and pose risks to human health. The re-invented natured-based solutions are facilitating water collection via infiltration of the water through layers of gravel of different types and dimensions, designed to increase the pollutant removal and enable the conveyance of water to the lower layers. Following infiltration, the water is conveyed to storing tanks for reuse. In the case of aboveground collection systems, such as retention ponds or wetlands, the water is treated by endemic plants or hydrophytes that enable pollutant removal and biodegradation of organic matter reducing the risk of point and diffuse pollution. If the systems are not connected with storage tanks or devices, the infiltrated or stored water enriches the groundwater aquifer, providing in this way high ecological, ecosystem, water and resources preservation benefits, while they contribute in closing the cycle of water use. Groundwater recharge does not only enrich a valuable water resource but it also protects the aquifer from salinization, in case of near the coast aquifers, from soil degradation and from land subsidence.

Conclusion – Looking ahead

The nature-based solutions have been appraised by the IUCN as beneficial to biodiversity and human well-being (2016), while in 2022 the International Federation of Red Cross and Red Crescent Societies (IFRC) and the WWF organization issued a report on the necessity of adopting Nature-based solutions. The savings on climate change relief measures, in developing countries only, from adopting nature-based solutions has been estimated to be at 104 billion US dollars until 2030 and 393 billion US dollars by 2050 (IFRC-WWF, 2022; ILO-UNEP-IUCN, 2022).

Frameworks, in which the use of nature-based solutions is included or implied, are the SDG (2015), the United Nations Framework Convention on Climate Change (UNFCCC, 1994) and the United Nations Convention to Combat Desertification (UNCCD). All the other policy frameworks refer to the more generalized term of ecosystem-based approaches, yet without compulsory character regarding implementation. Still there is a long list of policy documents, frameworks and initiative that refer to the necessity of adopting such interventions, such as: The resumed 5th session of the UN Environment Assembly (UNEA 5.2) resolution on Nature-based Solutions for Supporting Sustainable Development; Sendai Framework for Disaster Risk Reduction; Sustainable Development Goals (SDG); United Nations Framework Convention on Climate Change (UNFCCC); E.U. Water Framework Directive (2000); Convention on Biological Diversity (CBD); The Ramsar Conventions on Wetlands (Ramsar); United Nations Convention to Combat Desertification (UNCCD); New Urban Agenda (UN Habitat); European Green Deal; E.U. Horizon Programmes (The relevant strands of the E.U. Horizon 2020 included projects with a total budget of €282m); E.U. instruments (COST, ERDF, LIFE+ and EIB's Natural Capital Financing Facility) (Somarakis et al, 2019; Wild et al, 2020; UN, 2013; UN, 2015).

Overall, embracing nature-based solutions with water reuse potential presents a holistic approach to climate change adaptation and to providing a new water resource. They also address the principle of circular economy with financial and resource use benefits. By harnessing their multiple benefits, we can foster a more sustainable future that is resilient to climate change challenges while preserving the integrity of our ecosystems, the livelihood of our urban areas and supporting human and ecosystem well-being.

References

Apostolaki S. & Jefferies C. – Monograph (2009) 'The social dimension of stormwater management practices in urban areas - Application of Sustainable Urban Drainage Systems (SUDS) and River Management options', VDM Verlag Dr. Müller e.K. ISBN 978-3-639-17692-6, Paperback, 224 Seiten

Apostolaki. S. Jefferies. C. & Wild T. (2006) "The social impacts of stormwater management techniques", Water Practice & Technology, Volume 1, issue 1, IWA Publishing, August 2006, https://doi.org/10.2166/wpt.2006.009

EU EIT Climate KIC, [Apostolaki S., Berbel J., Casielles R., Consoli S., Cebollero E.D., Fatone F., Intrigliolo D.S., Masi F., Schmidt G., Rosado A.S., Skunca D., Tsani S.; Coordinated and Edited by Enyedi E.], 2021, White Paper on Innovative Solutions to Cope with Water Scarcity, December 2021

Eurostat – Statistics explained, 2023, Accessed on 14/05.2023, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Main_Page
IFRC - International Federation of Red Cross and Red Crescent Societies and WWF – World Wide Fund for Nature (Formerly World Wildlife Fund), Working with nature to protect people - How nature-based solutions reduce climate change and weather-related disasters, June 2022
IFRC-WWF, 2022, Working with nature to protect people. How nature-based solutions reduce climate change and weather-related disasters?, © Text 2022 WWF, IFRC.
ILO, UNEP and IUCN. 2022. Decent Work in Nature-based Solutions 2022, Geneva. Licence: CC BY-NC-SA 3.0 IGO
Morales-Torres, A., Perales-Momparler S. Jefferies C., Doménech I., 2015, Report on Stormwater Management, ©2015 E²STORMED Project
Somarakis, G., Stagakis, S., & Chrysoulakis, N. (Eds.)., 2019, ThinkNature Nature-Based Solutions Handbook. ThinkNature project funded by the EU Horizon 2020 research and innovation programme under grant agreement No. 730338. doi:10.26225/ jerv-w202
Tsani, S, Apostolaki, S, Koundouri, P. (2021). Policies and socio-economic tools for sustainable water management In Tsani, S., Overland I. (Eds.) The Sustainable Politics and Economics of Natural Resources. Edward Elgar Handbooks in Energy, the Environment and Climate Change, December 2021, DOI: https://doi.org/10.4337/9781789908770
UN Department of Economic and Social Affairs – Sustainable Development, the 17 SDGs, https://sdgs.un.org/goals Accessed 22.12.2023
UN WATER, 2020, The United Nations World Water Development Report – Water and Climate change
UN Water, 2022, The United Nations World Water Development Report 2022 – Groundwater: Making the Invisible Visible
UN, 2015, Sendai Framework for Disaster Risk Reduction 2015-2030
UNDESA – United Nations Department of Economic and Social Affairs, 2020, World Social Report 2020 Inequality in a Rapidly Changing World
UNESCO, UN Water - The United Nations World Water Development Report 4, 2012, Managing Water Report under Uncertainty and Risk
United Nations, 2022, The Sustainable Development Goals Report
Wild T., Bulkeley H., Naumann S., Vojinovic Z., Calfapietra C., Whiteoak K., 2020, Nature-Based Solutions State of the Art in EU-funded Projects, Directorate-General for Research and Innovation

Development of an NbS evaluation framework in the nexus of Sustainability, Circularity and Justice

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ABSTRACT

The unsustainable consumption of resources is one of society's major challenges and combined with the increasing global population and accelerating urbanization, it can produce severe environmental consequences. Although cities occupy only 3% of the world's surface, the share of the global population living in them is more than 55%. With an additional 2.5 billion people expected to live in cities, this percentage is expected to increase up to almost 70% by 2050 (United Nations, 2019). Processes conducted within cities or related to them consume 75% of the world's resources and generate half of all global waste. As a result, 50%–80% of the world's greenhouse gas emissions are attributed to urban areas (Lamia and Roberts, 2009). In addition, cities are facing various socio-economic problems, such as increasing inequalities, unemployment, poverty, and social exclusion (Li et al., 2021).

On the other hand, it is recognized that cities have the capability and the potential to lead the necessary transformation toward a more sustainable and resilient future (Klopp and Petretta, 2017). Cities are becoming focal players in driving sustainable transformation while maintaining economic growth and population wellbeing. Creating sustainable livable cities is one of the biggest urban challenges, and should come through various approaches, models, and strategies. The importance of this challenge is highlighted by the dedication of two Sustainable Development Goals (SDGs). SDG 11 aims to ''*make cities and human settlements inclusive, safe, resilient, and sustainable,*'' and SDG 12 aims to ''*ensure sustainable consumption and production patterns*.''

Potential solutions are emerging and one of these is the circular economy (CE) model, which is increasingly considered as a promising pathway to achieve sustainable urban development and tackle pressing sustainability challenges at the city-level (Chen, 2021). But to manage and control resource consumption in cities, flows of natural and industrial materials, energy, people, and information must be managed. Urban environments, like natural environments, are living systems, characterized by continuous flow of resources (energy, material, water, food). The interrelations between resource consumption, waste production and socio-economic activities within a city, are linked to its sustainability and thus assessment of the various flows can provide a measure of the urban sustainability (González et al., 2013).

The flow of resources through a (hypothetical) city was initially studied in 1965 by Wolman, who described such flows and their study under the concept of "urban metabolism". Since, concept of urban metabolism has been further studied and expanded it to include all types of flows and interactions within the urban environment, in order to include in the assessment, apart from energy, water, waste and pollutants, aspects of quality of life, biodiversity, mobility and socio-economic indicators (Kennedy, Pincetl and Bunje, 2011). By including environmental and socio-economic indicators along the study of inflow/outflow/stock of resources and waste, the urban metabolism concept offers an integrated and holistic approach to the assessment of urban sustainability.

The combination of the concepts of CE and UM to a new approach (Circular Urban Metabolism-CUM) for studying, designing, and managing sustainable cities seems very promising. This way of addressing the cities' problems can help designers and policymakers better understand how urban flows interact with the spaces over time and thus redesign and reorganize them more sustainably and resiliently. This could occur through applying the CE model at the city level, developing connections among flows (nexuses), and thus rethinking urban activities, redesigning urban and social infrastructures, and enhancing the reduction, reuse, and recovery of resources (Papageorgiou et al., 2021).

Structural interventions toward sustainable development can be achieved through Nature-based solutions (NbS). NbS has gained a lot of attention during the last decade, and they are defined as actions that protect, sustainably manage and restore natural or modified ecosystems. NbS can address societal challenges (e.g. climate change, food and water security, or natural disasters) effectively and adaptively, while simultaneously providing human well-being and biodiversity benefits (Cohen-Shacham et al., 2019). However, concerns are expressed that their application could sometimes neglect a significant part of society and their assets might be capitalized only by the urban elite. Hence the NbS planning, and implementation must acknowledge social needs and diversities and ensure environmental equality and justice during the transition to sustainable cities (Zuniga-Teran et al., 2021).

Therefore, there is a need for holistic tools that will help decision-makers design and implement NbS at the city level and then effectively monitor and evaluate the progress toward sustainability through CUM principles while assuring that the outcomes will equally affect all social groups. These tools should efficiently capture the “levels of circularity and social/ecological justice” and correlate the results to SDG. The application of such tools can provide useful information on how a city is performing in different areas, facilitate transparency and co-governance, and support investments in the green economy. These tools – will be based on indicators. In contrast to single indicators or indices that focus only on one specific aspect, indicator-based frameworks can address multiple dimensions and provide a more comprehensive picture of progress toward sustainability.

The aim of this study is to construct a multidimensional tool that will assist the NbS implementation based on a tailored (evolving) framework of indicators. The proposed framework will demonstrate the NbS performance in three dimensions simultaneously: CUM, Sustainability and Ecological Justice.

Methodology

The goal is to construct a tailored and adaptable framework that will associate improvements through NbS implementations to the cities’ environmental problems while addressing ecological injustices in urban areas. Therefore, the first step is to select and specify the urban challenges that the NbS are designed to tackle and mitigate. At the same time, the ecological space injustices correlated to these challenges must be identified and captured. The framework is based on a robust set of indicators that will both evaluate and monitor the progress and the application of the NBS and additionally examine whether the benefits of the NbS are equally shared by all social groups and heal existing (in)justices.

There are several indicators that can be connected to the whole or to specific stages of the NbS lifecycle (planning, development, implementation, monitoring, and performance evaluation). Detailed lists of NbS-related indicators, sorted per challenge area, have already been produced by EU funded projects, and such studies facilitate the initial selection. These indicators are then used to create the “basket” (set) of indicators that will be the skeleton of the evolving framework. The selection of the indicators is done according to the urban challenges and (in)justices that the NbS is designed to address. The next step is to evaluate and score the indicators regarding their potential to cover the specific needs of designing, monitoring, and evaluating the proposed NbS implementations. A literature review was performed to select the scoring methodology and a methodology based on the RACER criteria was finally adopted (Eisenmenger et al, 2016). Indicators are ranked according to 5 basic criteria and 10 subcriteria regarding their computation methodology, data requirements, and ease of use (Figure 1) using 0,1 and 2 as marks (2 corresponds to the higher score). In addition, indicators are scored on the same scale on their ability to capture basic CUM principles (Figure 1). The CUM criteria were defined considering literature recommendations on attributes that circularity metrics should have (Papageorgiou et al., 2011). Then, using the ON-OFF criterion, each indicator is rated for its ability to address specific SDGs and measure progress toward the selected SDGs. Finally, the indicators are evaluated (ON-OFF criterion) on their potential to address environmental injustices. Practically it is examined whether the indicators can be upgraded using spatially distributed demographic data, so their values are integrated within a population or across a geographical region.

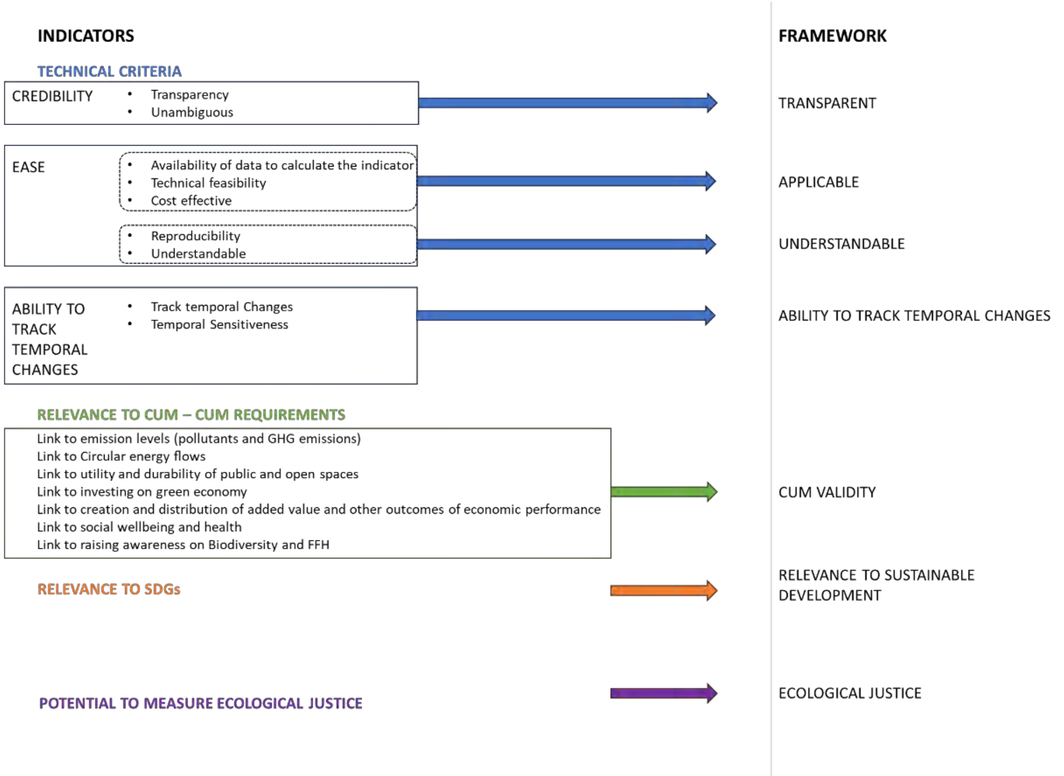

Figure 1. List of criteria and sub-criteria used for scoring the indicators and the framework

When the scoring is completed, indicators are selected, and the framework is formed. The performance of the framework is evaluated according to six selected criteria defined by the literature and associated EU-funded projects. The criteria are: (1) have a high level of transparency, (2) can track temporal changes, (3) be easily and effectively applicable, (4) be aligned to CUM, (5) be relevant to specific SDGs and (6) effectively capture ecological injustices. The fulfillment of the 3 first criteria is derived from the indicators' scores on their methodological requirements and ease of use (indicators' criteria 1-5). The indicators scoring for the CUM criteria define the alignment to CUM (framework criterion 4). Finally, the presence of indicators that can measure progress toward SDGs and capture ecological injustices evaluate the framework performance for criteria 5 and 6.

Case study

The developed framework was used to assist in the design and evaluate the performance of interventions based on NbS in the city of Chania (Crete, Greece). The interventions will take place in the city center, in a highly built up area with rather old buildings and lack of open and green spaces. The project aims to create green areas accessible to all citizens while mitigating GHG emissions, moderating heat stress and lowering air temperatures in the adjacent streets. The intervention consists of two parts: a) a green wall will be constructed in the municipality's five-story car park and b) a small urban park will be created in the open space in front of the parking building.

A tool to facilitate the selection and scoring of indicators was developed that can easily demonstrate the basic characteristics of the indicators and the scores according to the criteria described in the methodology section. The selection of indicators for the monitoring and evaluation was performed by an interdisciplinary group of representatives from the scientific advisor (Ember Lab, TUC), the company managing the parking (KYDON S.A), and the municipality authorities. When the indicator framework was completed a holistic picture of the intervention was created depicting the expected environmental outcomes, the compliance with CUM principles, the level of alignment to SDG, and the ability to address and mitigate injustices related to specific urban challenges in the city of Chania. The framework can be used as a tool to aid municipality authorities to evaluate future development plans based on NbS considering the expected outcomes but also their impacts on all social groups.

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References

Chen, C. W. (2021). Clarifying rebound effects of the circular economy in the context of sustainable cities. *Sustainable Cities and Society, 66*, Article 102622

Cohen-Shacham, E., Andrade, A., Dalton, J., Dudley, N., Jones, M., Kumar, C., ... & Walters, G. (2019). Core principles for successfully implementing and upscaling Nature-based Solutions. *Environmental Science & Policy*, *98*, 20-29.

Dumitru, A., & Wendling, L. (2021). *Evaluating the impact of nature-based solutions: A handbook for practitioners*. European Commission EC.

Eisenmenger, N., Giljum, S., Lutter, S., Marques, A., Theurl, M. C., Pereira, H. M., & Tukker, A. (2016). Towards a conceptual framework for social-ecological systems integrating biodiversity and ecosystem services with resource efficiency indicators. *Sustainability*, *8*(3), 201.

Kamal-Chaoui, Lamia and Alexis Robert (eds.) (2009), "Competitive Cities and Climate Change", OECD Regional Development Working Papers No 2, 2009, OECD publishing.

Kennedy, C., Pincetl, S. and Bunje, P. (2011) 'The study of urban metabolism and its applications to urban planning and design', *Environmental Pollution*. Elsevier, pp. 1965–1973.

Klopp, J. M., & Petretta, D. L. (2017). The urban sustainable development goal: Indicators, complexity and the politics of measuring cities. *Cities, 63*, 92–97.

Li, J., Sun, W., Song, H., Li, R., & Hao, J. (2021). Toward the construction of a circular economy eco-city: An emergy-based sustainability evaluation of Rizhao city in China. *Sustainable Cities and Society, 71*, Article 102956.

Papageorgiou, A., Henrysson, M., Nuur, C., Sinha, R., Sundberg, C., & Vanhuyse, F. (2021). Mapping and assessing indicator-based frameworks for monitoring circular economy development at the city-level. *Sustainable cities and society*, *75*, Article 103378.

United Nations, Department of economic and social affairs, population division. (2019). World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420). United Nations.

Zuniga-Teran, A. A., Gerlak, A. K., Elder, A. D., & Tam, A. (2021). The unjust distribution of urban green infrastructure is just the tip of the iceberg: A systematic review of place-based studies. *Environmental Science & Policy*, *126*, 234–245. https://doi.org/10.1016/j.envsci.2021.10.001

What do we know about the interactions between Nature-based solutions (NBS) and landscape?

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Keywords: NBS effectiveness; landscape management; indicators; well-being; perception

ABSTRACT

Nature-based solution (NBS) concept has been recently defined by the Resolution on Nature-based Solutions for Supporting Sustainable Development as *actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits* (UNEA-5, 2022). To fulfil these requirements, the landscape scale of NBS effectiveness and operational assessment is indicated as the most suitable one because of the various reasons. First of all, landscape values and quality affect the selection of NBS projects (Sowińska-Świerkosz & García, 2021), e.g. poor ecosystem conditions may be the main reason to undertake NBS action directed to restoration, whereas high value landscapes may benefit from the protection and conservation actions. Secondly, both synergies and trade-offs resulting from the implementation of micro-scale NBS extend beyond the physical borders of the area under implementation (Dumitru & Wendling 2021; IUCN, 2020; Sowińska-Świerkosz & García, 2022). Therefore, effectiveness of NBS should be analysed from the point of view of the expected landscape scale effects by demonstrating the upscaling potential of NBS (Groß et al., 2018; Solheim et al., 2021). Besides, a given intervention cannot be effectively managed in isolation. NBS planners and managers should take into account the interactions that occur across different social and ecological scales within the landscape (IUCN, 2020; Sowińska-Świerkosz & García, 2022). The importance of the proper selection of NBS scale is also underline by the IUCN global criteria (2020. One of the criterion states that: Design of NBS is informed by scale. It means that the design of NBS responds to the landscape-scale interactions between the economy, society and ecosystems by seeking synergies across different sectors. Despite the importance of research on NBS – landscape interactions, this issue is still one of the major knowledge gaps in the NBS studies (NetworkNature Report, 2021). It is challenging for researchers and managers to understand and assess how numerous and often individually micro-scale NBS can combine to deliver jointly significant strategies on landscape scale (IUCN, 2020; Nelson et al. 2020). The first stage to do so is to identify interactions between NBS and landscape in reference to ecological, social and economic spheres. Such knowledge would be helpful for the selection of optimal solution to be implemented, effective operational of existed NBS as well as to improve the management practices in the aim to strengthen the delivery of synergies at landscape scale and between the sectors.

Presented study aims to detect and name NBS-landscape interactions that are well documented in literature as well as to indicate those which require further analysis. The research was based on the critical analysis of the results of the systematic review of literature (Scopus database; 20th October 2022; search criteria 'nature-based solution' and 'landscape' in title, abstract, keywords; language: English). After the rejection of irrelevant records 58 matching studies were analysed. Four-stages screening procedure (title and abstract/entire paper screening by main/all authors) was adopted to detect so called 'context groups' that are understood as the way in which the NBS term/approach/project was used in relation to the notion of landscape, and vice versa how the notion of landscape was used in reference to NBS studies.

Results showed that among well-documented interactions between NBS and landscape are those which belong to five main context groups, called as: ‘Scale’, ‘Management’, ‘Tools’, ‘Perception’ and ‘Well-being’. Most of the analysed papers (19) consider the landscape as the scale of NBS project implementation, operational and management. Such understanding derives from the fact that any action working with nature needs to be implemented at suitable scale, which is e.g. the scale of the affected ecosystem or the scale of the landscape of outstanding values (Sowińska-Świerkosz & García, 2021; Zandersen et al., 2021). In most of the strategies, this is the ecosystem type and quality that condition the selection among actions aiming to protect, conserve, restore, sustainably use or manage ecosystems. The landscape-scale context also means that the implementation of an NBS action yields broader landscape-scale impacts, both in terms of synergies and trades-offs (IUCN, 2020). According to the analysed paper, the ecological and social impacts are much more empathised than the economic ones.

Second context group (represented by 14 papers) in based on the fact that landscape-based management contributions to the implementation of NBS actions. As being use for the long term, landscape planning and governance are used to identify and implement NBS strategies to address various societal challenges (Albert et al., 2019; Collier & Bourke, 2020). Here, landscape-based planning principles can be considered as the basis for creation and implementation of adoptive strategies of NBS governance that should be used for the regular monitoring and evaluation of the intervention outputs (IUCN, 2020; Sowińska-Świerkosz & García, 2021; Wang et al. 2021). On the other hand, this is a long-term future landscape vision what may be considered as a reason to undertake NBS actions: the NBS becomes a tool of the landscape vision realization (Gottwald et al., 2021).

Third context group is connected to the fact that landscape-based indicators are used as a tool to assess the impacts of NBS implementation. Their advantage derives from the fact that both, existed impacts of implemented NBS can be detected as well as the projected impacts of the planned solutions can be modelled and assessed in the aim to select the optimal solution to be implemented (Baldwin et al., 2022; Schmidt et al. 202; Sowińska-Świerkosz & García, 2021). These impacts, however, are usually analysed from the ecological perspective, including the assessment of spatial structure and configuration of landscape patches. These spatial characteristics of landscape are used as surrogates of ecological connectivity, diversity, and stability (Sowińska-Świerkosz et al., 2021). Therefore, next to them social sciences tools such as workshops and surveys as well as economic tools such as estimations are needed to fully analysed the NBS-landscape interactions.

Aesthetic interactions between NBS and landscape are quite well-documented in literature (examples are: EC, 2015; Gottwald et al., 2021; Li et al., 2022; Li and Nassauer, 2021; Wang et al., 2021). They directly refer to the social sphere of impacts. Users perceived in a certain way physical elements of NBS, not only by the sense of sight, but also by the sense of smell (e.g. flowers smell, smells from wastewater treatment plants) and hearing (e.g. birds singing, sound of working engineering infrastructure). In general, green and blue natural elements positively affect the visual values of landscapes (Wang et al., 2021), whereas elements of grey infrastructures, such as pipes, wind turbines, and artificial surfaces are typically viewed negatively or, if properly integrated into landscape as neutrally. As to most of the people the most important impacts of NBS implementation are those that affect their perception, the assessment of aesthetic interaction is crucial in order to obtain residents’ implementation support.

Last but not least, predominant share of NBS positive impact human well-being in terms of the mental and physical health and as so are connected to the ‘heath-supported’ landscape concept. Public gardens of different types, including community and allotment gardens, urban forest and flower meadow have the potential to provide multiple benefits simultaneously, including these supporting health and well-being (Dick et al., 2019; Dushkova & Ignatieva 2020). They re-connecting people with nature, favour spending time outdoor and motivate to start physical exercises. All these activities reduce stress, depression and strengthen the physical health (Dumitru & Wendling 2021; EC, 2015; Sowińska-Świerkosz et al., 2021).

Conducted review showed that detected interactions between NBS and landscape are mainly connected to the ecological and social spheres. Whereas, economic sphere is treated marginally. As a result, there is a lack of comprehensive studies that examine the NBS-landscape interactions. It was also showed that landscape type, its ecological quality and local environmental conditions to the greatest extend influence the selection and performance of NBS. Besides, results showed that the landscape-based principles and indicators positively influence the effective uptake of NBS actions. The future direction of NBS studies should be focused on the demonstration of the upscaling potential of NBS interventions to include ecological, social and economic outcomes beyond the area under the implementation.

References:

Albert, C., Schröter, B., Haase, D., Brillinger, M., Henze, J., Herrmann, S., Gottwald, S., Guerrero, P., Nicolas, & C., Matzdorf, B., 2019. Addressing societal challenges through nature-based solutions: How can landscape planning and governance research contribute? Landscape and Urban Planning 182, 12–21.

Baldwin, M., Fox, A., Klondike, T., Hovis, M., Shear, T., Joca, L., Hester, M., Cubbage, F., 2022. Geospatial Analysis and Land Suitability for "FloodWise" Practices: Nature-Based Solutions for Flood Mitigation in Eastern, Rural North Carolina. Land 11, 1504

Collier, M.J., & Bourke, M., 2020. The case for mainstreaming nature-based solutions into integrated catchment management in Ireland. Biology and Environment 120B, 107-113.

Dick, J. et al., 2019. How are nature based solutions contributing to priority societal challenges surrounding human well-being in the United Kingdom: a systematic map protocol. Environmental Evidence 8, 37.

Dumitru, A., Wendling, L., Eds. 2021. Evaluating the Impact of Nature-based Solutions: A Handbook for Practitioners. D-G R&I. Luxembourg: European Commission. DOI: 10.2777/244577

Dushkova, D., & Ignatieva, M., 2020. New Trends In Urban Environmental Health Research: From Geography Of Diseases To Therapeutic Landscapes And Healing Gardens. Geography, Environment, Sustainability 1,159-171.

European Commission 2015. Towards an EU Research and Innovation Policy Agenda for Nature-Based Solutions & Re-Naturing Cities. Brussels

Groß, E., Mård, J., Kalantari, Z., & Bring, A., 2018. Links between Nordic and Arctic hydroclimate and vegetation changes: Contribution to possible landscape-scale nature based solutions. Land Degradation and Development 1–11.

Gottwald, S., Brenner, J., Janssen, R., & Albert, Ch., 2021. Using Geodesign as a boundary management process for planning nature-based solutions in river landscapes. Ambio 50, 1477–1496.

IUCN 2020. Global Standard for Nature-based Solutions. A user-friendly framework for the verification, design and scaling up of NbS. First Edition. Gland, Switzerland: IUCN. Available from: https://portals.iucn.org/library/node/49070

Li, J., Nassauer, J.I., Webster, N.J., 2022. Landscape elements affect public perception of nature-based solutions managed by smart systems. Landscape and Urban Planning 221, 104355.

Li, H., Peng, J., Jiao, Y., Ai, S., 2022. Experiencing Urban Green and Blue Spaces in Urban Wetlands as a Nature-Based Solution to Promote Positive Emotions. Forests 13, 473

Nelson, D.R., Bledsoe, B.P., Ferreira, S., Nibbelink, N.P., 2020. Challenges to realizing the potential of nature-based solutions. Current Opinion in Environmental Sustainability 45, 49–55. DOI: 10.1016/j.cosust.2020.09.002

NetworkNature report on practical, research and innovation needs, 2022. https://networknature.eu/product/26244

Schmidt, S., Guerrero, P., Albert, C., 2022. Advancing Sustainable Development Goals with localised nature-based solutions: Opportunity spaces in the Lahn river landscape, Germany. Journal of Environmental Management 309, 114696.

Solheim, A., Capobianco, V., Oen, A., Kalsnes, B., Wullf-Knutsen, T., Olsen, M., Del Seppia, N., Arauzo, I., Garcia Balaguer, E., & Strout, J.M., 2021. Implementing Nature-Based Solutions in Rural Landscapes: Barriers Experienced in the PHUSICOS Project. Sustainability 13, 1461.

Sowińska-Świerkosz, B., & García J. 2021. A new evaluation framework for nature-based solutions (NBS) projects based on the application of performance questions and the indicators approach. Science of the Total Environment, 787, 147615.

Sowińska-Świerkosz, B., Wójcik-Madej, J., Michalik-Śnieżek, M., 2021. An assessment of the ecological landscape quality (ELQ) of nature-based solutions (NBS) based on existing elements of green and blue infrastructure (GBI) Sustainability 13(21), 11674.

Sowińska-Świerkosz, B., & García J., 2022. What are Nature-based solutions (NBS)? Setting core ideas for concept clarification. Nature-Based Solutions 2,100009.

UNEA-5 2022. Resolution on Nature-based Solutions for Supporting Sustainable Development. https://www.naturebasedsolutionsinitiative.org/news/united-nations-environment-assembly-nature-based-solutions-definition/

Wang, Z., Huang, L., Xu, M., & Wang, S., 2021. Bridging the science-practice gaps in nature-based solutions: A riverfront planning in China. Ambio 50, 1532–1550.

Zandersen, M. et al., 2021. Nature Based Solutions for Climate Adaptation - Paying Farmers for Flood Control. Ecological Economics 179,106705.

Integrating Yami/Tao Traditional Ecological Knowledge into Ecology Education: An Exemplification of Nature-Based Learning

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Keywords: Nature-Based Learning, Ecology education, Indigenous Experimental Education, Traditional Ecological knowledge, Tao/Yami, Lanyu (Orchid Island)

ABSTRACT

This study exemplifies the integration of Yami/Tao Traditional Ecological Knowledge into ecology education, showcasing the implementation of Nature-Based Learning. Indigenous education in Taiwan is currently in its early stages of development, and the principles of Nature-Based Learning align harmoniously with its fundamental values. The global and local Neonic pneumonia pandemic since 2020 has dramatically reshaped our lives, prompting a reevaluation of the importance of a healthy ecological environment. In addition to the necessity of digital and online courses, curriculum design and teaching practices should aim to cultivate not only students' academic knowledge and skills but also their ability to apply and transfer learned knowledge to real-life contexts.

To achieve these objectives, an ecology course was conducted at the Peinan Xikou National Important Wetland, conveniently and safely located near Taitung University, for three consecutive years from 2020 to 2023. During these outdoor teaching sessions, students were introduced to the rich traditional ecological knowledge of the Yami/Tao indigenous people. The results of the field trips were documented through group reports, and selected explanations provided by the instructor were included in the final exam.

Beyond extending the boundaries of the classroom, this course fostered a deep connection between students and the land. It aimed to enhance students' understanding of the local ecological system and bridge the gap between theoretical knowledge and practical experiences in the natural world. The exploration activities encompassed various ecological aspects, such as wetland ecology, plant and animal ecology, art ecology, landscape ecology, community ecology, and ecosystems.

By integrating Yami/Tao Traditional Ecological Knowledge into ecology education and exemplifying Nature-Based Learning, this study contributes to a more comprehensive understanding of ecological systems and their interrelationships. It underscores the importance of immersing students in authentic natural environments to facilitate their learning and appreciation of ecological concepts.

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Session B11: Water quality improvement for resource efficiency

Degradation of organic micropollutants in a modified OECD 308 test: implications for the use of reactive amendments in nature-based systems

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Keywords: micropollutants, river sediment, reactive materials, rate constant, half-lives, nature-based systems

ABSTRACT

In this study, a modified OECD 308 method was employed to determine the rate constant (*k*) and half-lives (DT_{50}) of selected organic micropollutants (OMPs). The method was proposed to estimate the persistence level of organic chemicals (including OMPs) in water-sediment systems (Coll et al., 2020; Seller et al., 2023). Adapting OECD 308 to man-made systems is considered a potential means to improve the understanding of pollutants traits and simulate pollutant removal features in the nature-based systems (NBS). Meanwhile, integrating reactive materials into NBS was formerly confirmed as one of intensification methods. Noteworthy, NBS as inherently vegetated systems may affect the reactivity of the amendments, e.g. by the interaction of plants exudates. To our knowledge, no attempts to verify the effect of plants exudates/reactive materials in NBS using the OECD 308 protocol were reported.

We tested the degradability of six OMPs i.e., sulfamethoxazole (SMX), 5-methylbenzotriazole (5MeBTR), diclofenac (DCF), bisphenol-S (BPS), metoprolol (MTP), and fipronil (FPN) for 183 days in incubated closed bottles. The oxygen availability was not adjusted assuming natural depletion based on the amount of available organic carbon. Firstly, the hydroponic boxes were set up in the greenhouse in a separate setting, filled with different solutions (synthetic greywater, half-, and two-fold concentrated Hoagland solution assumed to impose various magnitude of exudate release) and distinguished by planted (*Iris pseudacorus and Miscanthus sinensis*) and unplanted boxes (as negative controls). Secondly, after a three-day operation in the greenhouse, the solutions from hydroponic boxes were transferred into the bottles spiked with 4–7 mg/L of each selected OMPs. The bottles were grouped into different filling media namely 100% river sediment, 5:1 river sediment and manganese oxides (pyrolusite), and 5:1 river sediment and iron (III) hydroxides and oxide-hydroxides. Lastly, the bottles were divided into biotic-abiotic conditions (abiotic bottles were autoclaved and spiked with biocide, sodium azide). The reaction rate was regarded to follow the first-order kinetics. The variables that were considered governing the removal of selected OMPs i.e., biotic-abiotic conditions, filling media, solution type from hydroponic boxes, and planted mechanisms in hydroponic boxes.

The results showed that biotic-abiotic conditions had considerable effect on the degradation rate (*k*) of the OMPs over other main effects. Biotic conditions generally provided higher *k* and shorter *DT50* than abiotic ones ($p<0.05$). This may indicate that biodegradation was more responsible for OMPs removal than the abiotic mechanisms. However, such was not the case for FPN which was removed rapidly in both conditions (average *DT50*= 5.2 and 8.8 days in abiotic and biotic bottles, respectively). The addition of iron-based material in filling media promoted the degradation for SMX (k=0.056±0.057 1/d) and BPS (k=0.03±0.013 1/d), while manganese oxides were superior for DCF (k=0.049±0.022 1/d). The addition of reactive materials did not affect MTP removal by which 100% river sediment was significant ($p<0.05$, *DT50* ≈ 38 days). Besides, no significant differences were observed between the effect of solution either from planted or unplanted boxes. Specifically, the solution from unplanted boxes enhanced the degradation rate of 5MeBTR compared to that of planted boxes. Meanwhile, SGW generally improved the degradation of all selected OMPs ($p<0.05$), except for DCF and FPN. The *DT50* average from the lowest to highest in SGW solutions was 5MeBTR (43.4 days), BPS (46.8 days), and SMX (56.9 days). In summary, our study

indicated that predominantly biodegradation affected the OMPs removal features, and the addition of reactive materials contributed only to certain OMPs removal, but there was no synergy between plant exudates and the reactive materials. We are continuing to identify microbial communities in the biotic bottles for further evaluation and the quantity and quality of plant exudates (beyond the indirect analysis of TOC, TN, and other parameters).

Acknowledgments:
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References:

Coll, C., Bier, R., Li, Z., Langenheder, S., Gorokhova, E., & Sobek, A., 2020. Association between aquatic micropollutant dissipation and river sediment bacterial communities. Environmental science & technology, 54(22), 14380-14392.

Seller, C., Varga, L., Börgardts, E., Vogler, B., Janssen, E., Singer, H., Fenner, K., & Honti, M., 2023. Do biotransformation data from laboratory experiments reflect micropollutant degradation in a large river basin? Water Research, 235, 119908.

Degradation of perfluoroalkyl and polyfluoroalkyl substances (PFAS) in secondary effluent by nonthermal plasma: role of reactive oxidative and reductive species

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Keywords: Advanced reduction processes, Advanced oxidation processes, Defluorination, Nonthermal plasma, Perfluoroalkyl and polyfluoroalkyl substances

ABSTRACT

The widespread use of perfluoroalkyl and polyfluoroalkyl substances (PFAS) in the last century has caused serious pollution of water bodies around the world, which seriously threatens the health and survival of humans or other organisms. In this work, a novel cascade reactor configuration, comprised a dielectric barrier discharge (DBD) plasma chamber, connected in series with a preceding ozonation chamber was used to treat PFAS-containing wastewater. The Electrical Energy per Order (EE/O) for removal of PFBA, PFHxA, PFOA and PFDA from secondary effluent after 60-min reaction were 384, 63, 18 and 10 kWh/m^3, respectively. While the short-chain PFAS were difficult to be removed, more than 90% of the longer PFAS were degraded. Compared with past studies, a smaller amount of energy input was required to degrade PFAS. This is because the presence of ozonation chamber enhance the utilization of long reactive species, and the negative influences of coexisting ions and substances were mitigated. When the secondary effluent containing PFAS was treated, the defluorination efficiency was increased by 5% due to the presence of ozonation chamber. Reactive reductive species play a direct role in defluorination, whereas reactive oxidative species contribute indirectly by eliminating coexisting ions and substances, thus preventing the depletion of reactive reductive species. Perfluoroalkyl carboxylic acids (PFCAs) generated during the plasma reactions may have a potential risk for environment. As such, full mineralization should be considered.

Introduction

Per- and polyfluoroalkyl substances (PFAS) are a category of man-made organic chemicals that are extensively utilized in various fields such as metal plating, semiconductors, firefighting materials and food packaging [1]. Human PFAS exposure can cause immune suppression, endocrine disruption, cancer and malformed foetus. Addressing the degradation of PFAS in the environment has become a hot research topic in various countries.

PFAS exhibit exceptional stability and persistence due to the remarkably high energy of the carbon-fluorine bonds, which renders them resistant to thermal, chemical, and biological degradation. Nonthermal plasma-based technology is considered a promising technology for degrading PFAS [2-4]. While generating a range of reactive oxidative species such as •OH, O, $O_2^{\bullet-}$, $_1O^2$, O_3, and H_2O_2, plasma can also produce reactive reductive species including hydrated electrons (e_{aq}^-), H•, Ar^+, and Ar* [5]. Although nonthermal plasma-based technology has shown great potential to treat PFAS, there are significant hurdles to overcome. The role of reactive reductive species has been extensively studied in the past, but the role of reactive oxygen species was always underestimated. The complex compositions of wastewater matrices, such as dissolved organic matters (DOM) and inorganic ions, consume reactive species, which inhibit the degradation of PFAS. Additionally, the utilization of reactive species is very low according to previous literature [6, 7], and many long-life reactive species that do not have sufficient time to contribute to the degradation of PFAS are wasted.

To mitigate the impacts of complex compositions of wastewater matrices and maximize the utilization of reactive species, a novel cascade reactor configuration was developed for degrading PFAS from secondary municipal wastewater effluent. It comprises a dielectric barrier discharge (DBD) plasma chamber, connected in series with a preceding ozonation chamber. The role of reactive oxidative and reductive species was systemically evaluated. These findings offer valuable insights into the development of nonthermal plasma technology that can be scaled up for the treatment of PFAS-contaminated water.

Materials and Methods

Figure 1 displays a diagrammatic representation of the reactor. The reactor comprises a dielectric barrier discharge (DBD) plasma chamber, connected in series with a preceding ozonation chamber (Details are presented in our previous works [8]). A volume of 600 mL wastewater (synthetic or secondary effluent) was added to the reactor. Wastewater was exchanged between the ozonation chamber and the plasma chamber via the inner channel of a stainless-steel tube at a pre-set liquid flow rate (100 mL/min). In the plasma chamber, the waste water was introduced at the top, forming a water-falling film on a porous Cr_2O_3 layer. The wastewater at the bottom of the plasma reactor was pumped to the ozonation chamber. The carrier gas (Ar) was introduced from the bottom of the plasma chamber to the reactor at 0.4 standard liter per minute (SLM). The reactive species generated in the plasma zone were carried into the ozonation chamber through an aeration device. The discharge power was pre-set as 60 W. The wastewater was sampled after a pre-set reaction time of 10, 20, 30, 40, 50, and 60 min. The defluorination and degradation efficiency, electrical energy per order (EE/O) were used to evaluate the reactor performance.

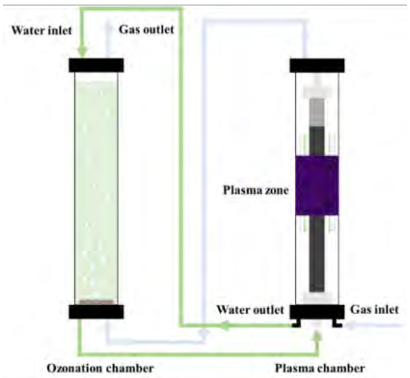

Fig. 1. Schematics of the nonthermal plasma reactor.

Results and discussion

PFAS degradation efficiency and energy consumption

Wastewater was fed into the plasma reactor, and the degradation and energy efficiency of PFAS were shown in Figure 2. The degradation efficiencies of PFBA, PFHxA, PFOA and PFDA in synthetic wastewater were 11%, 32%, 80% and 90%, respectively (See Figure 2(A)). The degradation efficiency of PFAS was significantly increased with the increase of carbon chain length. The hydrophilic and hydrophobic properties of PFAS also affect their degradation. The hydrophobicity of molecule is improved when the carbon chain increases. PFAS with a long carbon chain always exist in the gas-liquid interface due to their strong hydrophobicity. However, the life-times of main reactive species are very short [10]. Therefore, PFAS near the phase interface will be preferentially degraded. The degradation efficiencies of PFAS in secondary effluent were only 2-8% lower than that the synthetic wastewater (See Figure 2(B)). It indicates that the non-thermal plasma reactor has the potential to treat real wastewater.

The energy efficiencies of PFAS in synthetic wastewater were shown in Figure 2(B). The EE/O of PFOA and PFDA in synthetic wastewater and secondary effluent were 10-16 and 10-16 kWh/m^3, respectively. Compare to the energy consumption for synthetic wastewater, the extra energy consumption for secondary effluent was not more than 2 kWh/m^3. Compare to the previous works, the degradation and energy efficiency have remarkable advantages to treat PFAS-containing wastewater.

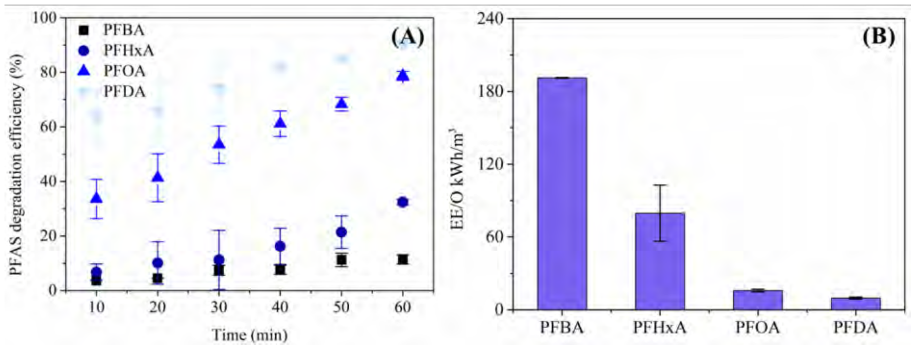

Figure 2. Degradation efficiency and energy consumption of PFAS-containing wastewater treated by nonthermal plasma-based technology.

Contribution of ozonation and plasma

Wastewater was treated by ozonation alone, plasma alone and plasma & ozonation, respectively. The degradation efficiency of PFAS treated by plasma & ozonation was the highest (PFOA 79%, PFDA 90%), follow by plasma alone (PFOA 78%, PFDA 83%), ozonation alone (PFOA 12%, PFDA 15%), as shown in Figure 3 (A). Most PFAS were degraded in plasma chamber, and very low degradation efficiency of PFAS was obtained in ozonation chamber. Because the plasma chamber contains a greater diversity of reactive species compared to the ozonation chamber. Due to the high voltage discharge, reactive oxidative species (•OH, O, $O_2^{\bullet-}$, $_{1}O^{2}$, O_3, and H_2O_2) and reactive reductive species (e_{aq}^{-}, H•, Ar^{+}, and Ar*) were generated in the plasma zone. Long-life reactive species (O_3 and H_2O_2) in ozonation chamber as well as a few free radicals (•OH) generated by the decomposition of O_3 and H_2O_2. Although it has been proved that O_3 and H_2O_2 can not directly degrade PFAS, •OH can cleave carbon bonds and separate end groups of PFAS [11]. Thus, a small amount of PFAS was degraded in ozonation chamber.

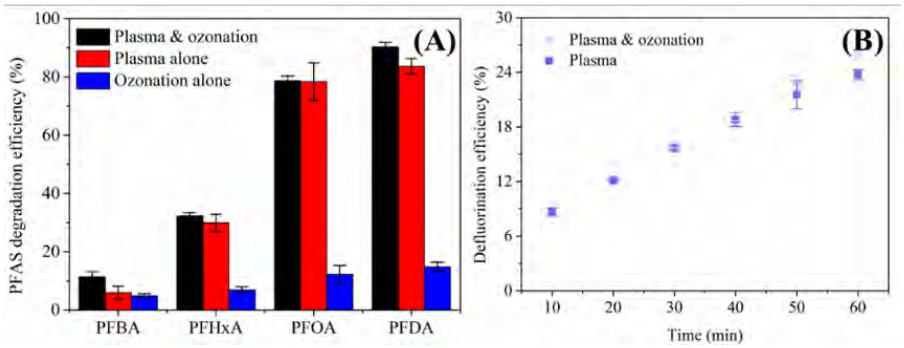

Figure 3. The degradation and defluorination efficiencies of PFAS treated by ozonation alone, plasma alone and plasma & ozonation. (A) Degradation efficiency of PFAS in synthetic wastewater, (B) Defluorination efficiency of PFAS in synthetic wastewater.

The defluorination efficiencies of PFAS treated by plasma alone and plasma & ozonation were found to be similar, differing by no more than 2% (See Figure 3 (B)). Fluoride ions were not detected treated by ozonation alone. This indicates that defluorination was only taking place in the plasma chamber and that defluorination mainly depended on the action of reactive reductive species. The lifetime of reactive reductive species is only a few nanoseconds [10], making it impossible for them to exist in ozonation chamber. As such, no defluorination takes place in ozonation chamber.

The defluorination efficiency of PFAS in secondary effluent treated by plasma alone was about 5% lower than that of secondary effluent treated by plasma & ozonation. Compared to synthetic wastewater, the difference in defluorination efficiency when using plasma alone or plasma & ozonation is more significant. Coexisting inorganic ions and organic matters can consume reactive reductive species, which impedes defluorination. The presence of ozonation chamber can not remove fluoride directly, but can eliminate the negative influences of coexisting inorganic ions and organic matters. Due to the presence of ozonation chamber, more inorganic ions and organic matter was removed and less reactive reductive species can be quenched. Thus, a higher defluorination efficiency was achieved after treatment with plasma & ozonation.

When the cascade reactor of plasma and ozonation was used to treat the real industrial PFAS-containing wastewater, the presence of ozonation chamber can play a very important role to eliminate the negative influences of coexisting components.

Conclusions

In this study, a novel cascade reactor configuration, comprised a dielectric barrier discharge (DBD) plasma chamber, connected in series with a preceding ozonation chamber was used to remove 4 PFAS with different carbon chain length in secondary effluent. The degradation efficiencies of PFBA, PFHxA, PFOA and PFDA in secondary effluent after 60-min reaction were 6%, 31%, 72% and 88%, respectively. Most long chain PFAS can be degraded, but the degradation of short chain PFAS is still challenging. More than 90% of the PFAS was degraded in the plasma chamber, while the PFAS degradation in ozonation chamber was limited. The presence of ozonation chamber will not greatly increase the degradation efficiency of PFAS, but can reduce the scavenging of reactive reductive species by coexisting ions in real wastewater. This is important for treating real wastewater containing PFAS. The indirect involvement of reactive oxidative species in PFAS mineralization by removing scavengers of reactive reductive species is highlighted for the first time in this study. The results of this study provide an effective solution for treating municipal or industrial wastewater containing PFAS, which is conducive to control and remedy PFAS pollutions.

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References:

[1] J. Li, X. Li, Y. Da, J. Yu, B. Long, P. Zhang, C. Bakker, B.A. McCarl, J.S. Yuan, S.Y. Dai, Sustainable environmental remediation via biomimetic multifunctional lignocellulosic nano-framework, Nature Communications 13(1) (2022) 4368. https://doi.org/10.1038/s41467-022-31881-5.
[2] J. Cui, P. Gao, Y. Deng, Destruction of Per- and Polyfluoroalkyl Substances (PFAS) with Advanced Reduction Processes (ARPs): A Critical Review, Environmental Science & Technology 54(7) (2020) 3752-3766. https://doi.org/10.1021/acs.est.9b05565.
[3] R.K. Singh, N. Multari, C. Nau-Hix, S. Woodard, M. Nickelsen, S. Mededovic Thagard, T.M. Holsen, Removal of Poly- and Per-Fluorinated Compounds from Ion Exchange Regenerant Still Bottom Samples in a Plasma Reactor, Environmental Science & Technology 54(21) (2020) 13973-13980. https://doi.org/10.1021/acs.est.0c02158.
[4] R.K. Singh, N. Multari, C. Nau-Hix, R.H. Anderson, S.D. Richardson, T.M. Holsen, S. Mededovic Thagard, Rapid Removal of Poly- and Perfluorinated Compounds from Investigation-Derived Waste (IDW) in a Pilot-Scale Plasma Reactor, Environmental Science & Technology 53(19) (2019) 11375-11382. https://doi.org/10.1021/acs.est.9b02964.
[5] R.K. Singh, S. Fernando, S.F. Baygi, N. Multari, S.M. Thagard, T.M. Holsen, Breakdown Products from Perfluorinated Alkyl Substances (PFAS) Degradation in a Plasma-Based Water Treatment Process, Environmental Science & Technology 53(5) (2019) 2731-2738. https://doi.org/10.1021/acs.est.8b07031.
[6] N. Wardenier, P. Vanraes, A. Nikiforov, S.W.H. Van Hulle, C. Leys, Removal of micropollutants from water in a continuous-flow electrical discharge reactor, J Hazard Mater 362 (2019) 238-245. https://doi.org/10.1016/j.jhazmat.2018.08.095.
[7] R.K. Singh, L. Philip, S. Ramanujam, Rapid degradation, mineralization and detoxification of pharmaceutically active compounds in aqueous solution during pulsed corona discharge treatment, Water Res 121 (2017) 20-36. https://doi.org/10.1016/j.watres.2017.05.006.
[8] C. Chen, C. Ma, Y. Yang, X. Yang, K. Demeestere, A. Nikiforov, S. Van Hulle, Degradation of micropollutants in secondary wastewater effluent using nonthermal plasma-based AOPs: The roles of free radicals and molecular oxidants, Water Research 235 (2023) 119881. https://doi.org/https://doi.org/10.1016/j.watres.2023.119881.
[9] C. Chen, C. Ma, X. Yang, K. Demeestere, A. Nikiforov, S.W.H. Van Hulle, Phosphorus recovery from phosphonate-contaminated wastewater by nonthermal plasma treatment prior to adsorption on granular iron-coated sand, Chemical Engineering Journal 464 (2023) 142753. https://doi.org/https://doi.org/10.1016/j.cej.2023.142753.
[10] B. Jiang, J. Zheng, S. Qiu, M. Wu, Q. Zhang, Z. Yan, Q. Xue, Review on electrical discharge plasma technology for wastewater remediation, Chemical Engineering Journal 236 (2014) 348-368. https://doi.org/10.1016/j.cej.2013.09.090.
[11] M. Gar Alalm, D.C. Boffito, Mechanisms and pathways of PFAS degradation by advanced oxidation and reduction processes: A critical review, Chemical Engineering Journal 450 (2022) 138352. https://doi.org/https://doi.org/10.1016/j.cej.2022.138352.

Techno-Economic Feasibility Analysis (TEFA) of the Advanced Primary Filtration (APF) process as a retrofit system at the municipal Wastewater Treatment Plant (WWTP) of Marpissa, Paros, Greece

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Keywords: Wastewater treatment plant; primary filtration; energy savings; capacity increase.

ABSTRACT

The high energy consumption of Wastewater Treatment Plants (WWTPs) is a major concern for municipalities worldwide (Siatou et al., 2020). The early removal of suspended solids, before entering the aeration tank, provides significant benefits for new and existing WWTPs, as it will enhance the efficiency of downstream biological treatment, will reduce the plant footprint, and the reduced capital and operating costs, compared to conventional wastewater treatment process (Gikas, 2017).

An Advanced Primary Filtration (APF) system is currently under installation, as retrofitting process at the existing activated sludge WWTP of Marpissa, Paros, Greece, with is expected to double due to the expansion of the sewerage network, reaching a maximum hydraulic capacity of 2,500 m^3/d. A Techno-Economic Feasibility Analysis (TEFA) was conducted to evaluate the potential economic benefits of installing the APF system to retrofit the WWTP of Marpissa, under increased loading. Wastewater loading is expected to increase in WWTP of Marpissa, due to the expansion of the sewerage network. The APF process comprises of a microscreen (which functions as primary solids removal system), followed by a Continuous Backwash Upflow Media Filter (CBUMF) and a lamella settling tank (for the thickening of the CBUMF reject water) (Gikas, 2017). The biosolids produced from the microscreen (with solids concentration of about 30%), will be ideal for the production of fertilizer (through composting) or for energy production (through either biological or thermal processes). In the second step of APF, the CBUMF will remove a significant fraction of the remaining suspended solids, assisted by the dosing of a coagulation agent. The reduction the organic load entering the aeration tank will increase the plant treatment capacity with no need for expanding the aeration tank, utilizing less electric energy per volume of incoming wastewater. Thus, the installation of the upfront solids removal system is anticipated to increase the WWTP capacity by about 40%. Downstream of the APF process, the TSS and BOD_5 are expected to be reduced by about 90 and 60%, respectively. Consequently, the total electricity consumption by the retrofitted WWTP is expected to be reduced by 25%, compared to the current situation. The decrease in electricity consumption will reduce greenhouse gas emissions of the existing WWTP by an estimated 3.30 t $CO_{2e}y^{-1}$. As a result, the annual operation cost for the complete treatment of raw wastewater, per volume of inlet raw wastewater, was calculated to be 0.34 €/m^3 and 0.32 €/m^3 for the existing and retrofitted WWTP, respectively; while the capital cost required for installing the APF system has been calculated as 18,00% lower of the cost required for conventional expansion of the Marpissa WWTP.

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References:

Siatou, A., Manali, A., & Gikas, P. (2020). Energy consumption and internal distribution in activated sludge wastewater treatment plants of Greece. Water, 12(4), 1204.

Gikas, P. (2017). Towards Energy Positive Wastewater Treatment Plants, J Environ Manage, 203 (2), 621-629.

Quantifying the effects of grazing beef cattle on microbial quality of surface water

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Keywords: Watershed management policy, Spatial and temporal study, Cattle feces, Pasture, Microbial water quality

ABSTRACT

In the last two decades, increasing interest has been paid to the transport and fate of fecal-borne pathogenic vectors (bacteria and viruses) in the environment. The US Environmental Protection Agency has been tasked with identifying impaired water sources due to fecal contamination and developing strategies for the control and management of these vectors (US-EPA, 2014). Today, animal waste and excrement are recognized as important causes of fecal contamination in the environment and specifically in surface water (streams, lakes, etc. via rainfall run-off. Thus, for surface waterbodies that are used for supplying water (drinking/ irrigation) or watercourses serving as tourist attractions, information on the animal contribution of pathogens is required. These animals can be wildlife (e.g. wild boars, jackals, etc.), avians, or domesticated animals (especially grazing beef cattle). Data on contributing animals can be acquired from monitoring devices such as global positioning systems (GPS) combined with sensing devices, which can monitor the spatial distribution of livestock activities. However, these devices can operate for a limited time (a few days) due to battery life and entail high costs, making them unfeasible in most cases. Observation of the spatial distribution of animal excreta is much simpler and provides a better understanding of environmental pollution potential from agricultural operations (i.e., beef cattle grazing; Yoshitoshi et al., 2020) and could aid management practices for mitigating pathogens levels in water sources. A thorough understanding of the environmental factors that promote the presence of livestock in a certain area and thus increase the potential for contamination is critical for evaluating management practices aimed at decreasing water bacterial/viral contamination originating from animals' excretion.

Hassan-Vásquez et al. (2022) investigated various factors affecting the accumulation of grazing cattle feces around water troughs including land slope, exposure to the sun, shading, and distance from the water source in addition to time-dependent factors such as weather and vegetation. They indicated that cattle showed a preference for flat surfaces and areas close to the water when most of the feces were found at a distance of 50 to 100 m from the water trough. Closeness to the water trough was also mentioned by Yoshitoshi et al. (2020) in addition to higher green herbage biomass, when feces tended to be distributed in these areas.

The main objective of this study was to create a database that would be useful for public health risk assessment and for supporting the derivation of management policy for reducing fecal risk. Thus, data provided by spatial observation surveys, were evaluated, together with information about farm area characteristics and weather conditions, to describe cattle feces distribution in pasture areas, paying special attention to the identification of hotspots and their characteristics.

Seven seasonal observation surveys were performed between May 2022 to February 2023 at Lake Kinneret watershed (Sea of Galilee, North of Israel), total of 9 pasture fields were scanned, each contains at least one water body (e.g.: pool/stream/ trough, table 1).

Table 1: Grazing data of the scanned fields

Filed	Water source	Grazing density (cows/1,000 m^2)	Number of grazing cows	Type of grazing	Grazing period (Number of days a year)
1	Trough	18	40	Continuous	365
2	Pool and trough	9	32	Seasonal	~200
3	Pool and trough	18	15	Seasonal	~240

4	Stream	25	~100	Continuous	365
5	Spring	4	85	Freq. Chng *	~14
6	Spring	4	85	Freq. Chng	~14
7	Stream	~25	Unknown	Continuous	365
8	Spring	~25	~50	Continuous	365
9	Stream and trough	2	~130	Freq. Chng	~14

* Freq. Chng – High animal density for a short time period with frequent changing of plots

Cattle feces were mapped at each field along 2-6 sections each 100-500 m long. Some of the sections began at the water source while others were randomly picked at the field (Figure 1). Data of feces location (coordinates), size (length, width, and depth), visually estimated categorical age-group and geographic characteristic (shadow, hill, road, etc.) was collected using GIS collector app. Feces age-group was classified visually to 3 categories: 1) Fresh- up to one week; 2) Medium – 1-3 weeks and 3) Old - above three weeks.
All feces located at 5 m radius m from the mapped feces were counted and the total density was calculated at 2 m width. In addition, samples of feces were taken on ice to the laboratory for measuring water content and fecal coliforms (FC) concentration.
Feces mapping was performed both during summer and winter at fields having point-source water (trough/pool) and non-point source (stream), indicate decreasing feces density with distance from the water sources, with no noticeable significant difference between types of water sources (Figure 2). Winter sampling included scanning an area more than 100 m from the water source, in order to obtain better information on the distribution of the feces in the fields. This mapping revealed contrary to plain logic high feces density far from the water source. These locations were found to be relatively high areas (topographically), and it is hypothesized that the preference for windy places (which have cooling effects) also affects the location of cattle. Other areas with high feces density, located far from the water source, were shaded areas that were used as resting places for the cows.
Classifying the cattle feces to three categories was found to correlate with water content, where statistically significant water content was found between the three categories (Figure 3), on the other hand, significant correlation between FC concentration and the three categories was not found.
Generally, FC concentration increased with water content indicating the need of bacteria for moist environment to exist (Figure 4). However, the obtained correlation (although statistically significant) explains only 38% of the variance, meaning that also other variables influence FC concentration in the feces. It should be noted that FC concentration measured in fresh feces (excreted during the survey), was lower than in feces of age category 1 (up to one week). These results led to the hypothesis that FC concentration increase during the first days after excretion, due to convenient conditions in the feces (un-limited resources: water, organic material, nutrient, etc.) and favorable conditions (temperature, moisture) and when conditions start to worsen FC concentration decreases.

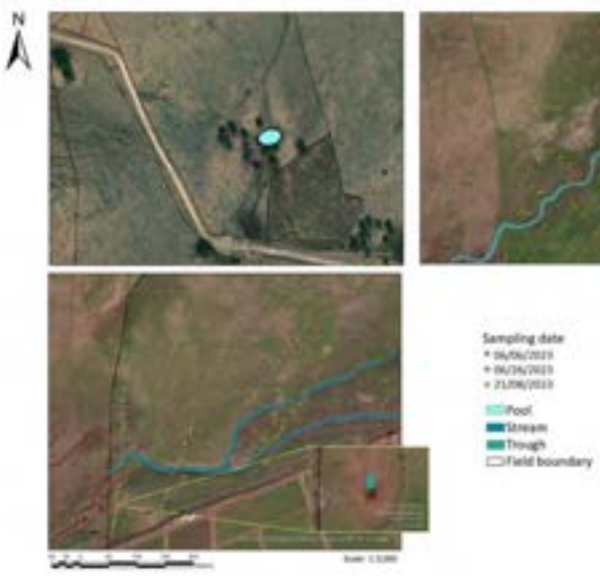

Figure 1: Scanned sections at field # 2 (top left), # 5 (top right) and # 9 (bottom left).
Circles represent feces that were mapped using the collector app.

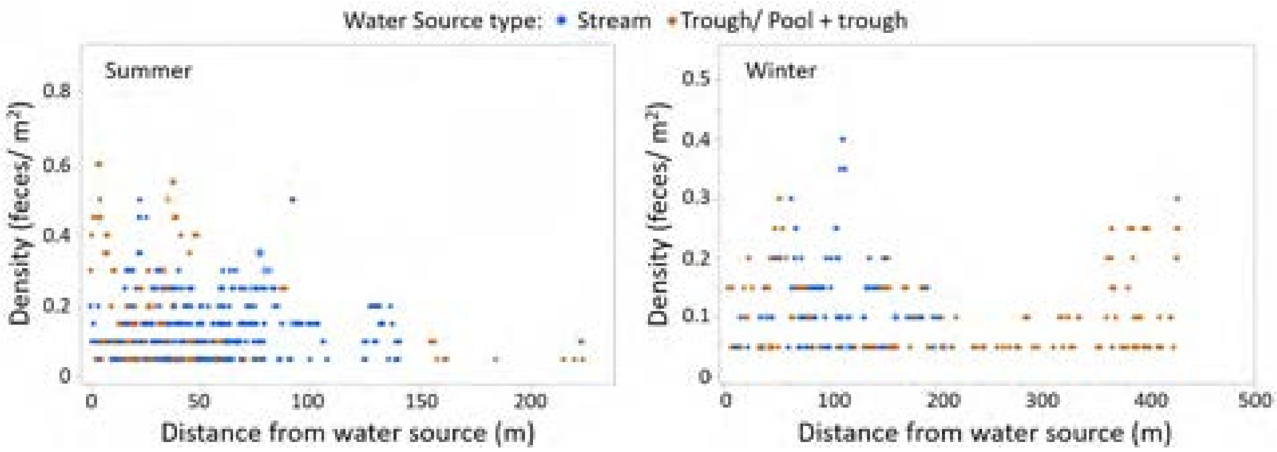

Figure 2: feces density vs. distance from water source (* indicated feces found at the shade).

Our results illustrate the opportunities to reduce the risk of water quality contamination by strategic placement of cattle attractants and provide a means to predict cattle feces deposition based upon inherent watershed characteristics and management factors.

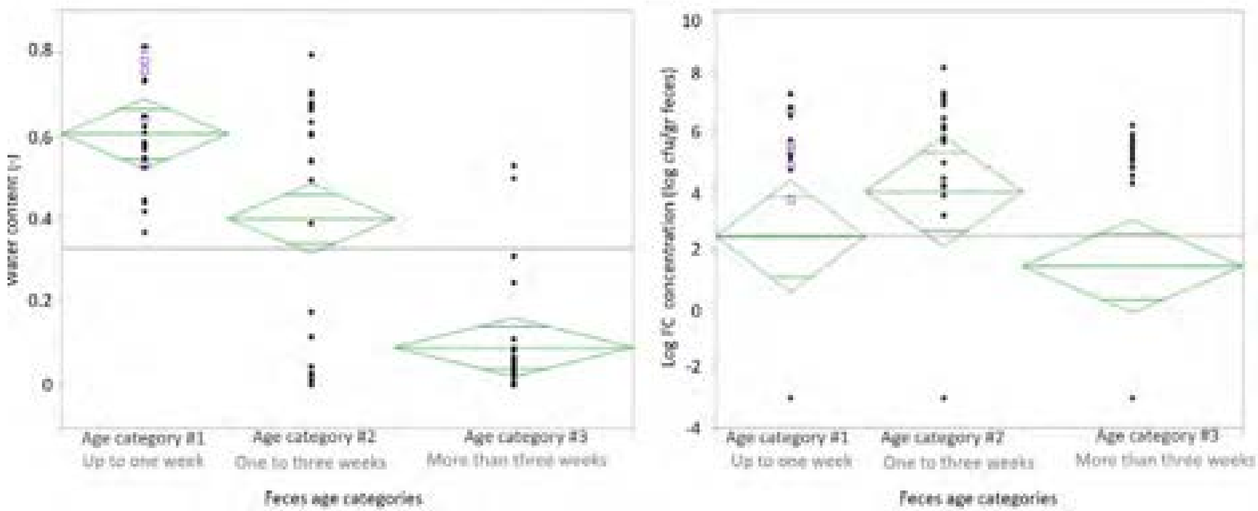

Figure 3: Water content and log FC concentration vs. feces age categories (set by visual observation).
Purple squares - Fresh feces excreted during the survey day

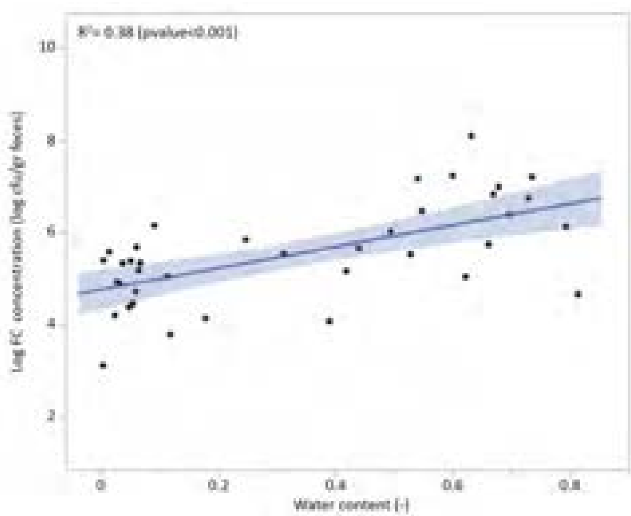

Figure 4: Log FC concentration vs. water content

Acknowledgements

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References:

Hassan-Vásquez, J. A., Maroto-Molina, F., & Guerrero-Ginel, J. E., 2022. GPS Tracking to Monitor the Spatiotemporal Dynamics of Cattle Behavior and Their Relationship with Feces Distribution. *Animals*, *12*(18), 2383.

US EPA, 2014. Clean Water Act Section 303(d): Impaired Waters and Total Maximum Daily Loads (TMDLs). https://www.epa.gov/tmdl.

Yoshitoshi, R., Watanabe, N., & Lim, J., 2020. Spatial Distribution of Grazing Sites and Dung of Beef Cows in a Sloping Pasture. *Japan Agricu*

ltural Research Quarterly: JARQ, *54*(4), 299-306.

Occurrence of ESKAPE pathogens in wash waters of the agri-food industry in view of the implementation of a closed loop economy

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Keywords circular economy, water purification, agro-food industry, ESKAPE pathogens, wash-water.

ABSTRACT

Progressive climate change poses a serious threat to aquatic ecosystems, which are reservoirs of water for humans. Currently, more than a quarter of the human population is exposed to drinking water shortages, with negative impacts on human health and life, animal welfare and agri-food production (UN Water, 2018; Vanham et al., 2021). The food industry is one of the economic sectors with high water consumption. In particular, the fruit and vegetable sector requires a significant amount of water for the pre-processing of raw materials, and agricultural activities alone consume 70% of the world's freshwater resources (Aivazidou et al., 2017; Gil et al., 2009; Jagtap et al., 2022). In fruit and vegetable processing plants, water is mainly used to pre-treat raw materials from soil and contaminants, and to rinse peeled produce. According to estimates, processing 1 kg of fruit and vegetables requires 5 litres of water in post-harvest processing. Thus, this results in the generation of wastewater, whose physico-chemical and biological properties largely depend on the type of raw material being processed. It is noteworthy that not all facilities recycle rinse water, which leads to a waste of resources and the creation of additional costs, which in turn can negatively affect the economic health and competitiveness of companies (Lehto et al., 2014; Mundi et al., 2018). It is therefore necessary to increase investment, resource allocation and undertake greater efforts to reduce water consumption by implementing sustainability principles in the agri-food production sector. One of the challenges of treating rinse water in agri-food facilities is that the water usually contains a considerable amount of solids and organic matter, which significantly affects the treatment processes (Mundi et al., 2018). On the other hand, wash waters may contain a significant number of microorganisms, which contributes to the costliness of the treatment process (Allende et al., 2008). Microbiological monitoring of rinse water is prophylactic due to the risk of potential cross-contamination between consecutive batches of raw material. There is a serious public health risk associated with pathogen contamination, especially for minimally processed products, which can lead to outbreaks. In addition, the presence of rinse water can promote the spread of saprotrophic microorganisms, which negatively affects the quality of the final product (Lapidot et al., 2006; Mritunjay and Kumar, 2017). Of particular concern are microorganisms belonging to the ESKAPE group, which includes alert pathogens such as *Enterococcus faecium, Staphylococcus aureus*, *Klebsiella pneumoniae*, *Acinetobacter baumannii*, *Pseudomonas aeruginosa* and *Enterobacter* spp. These are highly virulent and antibiotic-resistant bacteria, posing an additional threat to public health (Jabbari Shiadeh et al., 2019).

The aim of the study was to carry out a microbiological safety assessment of process water, used for washing and cleaning processes of raw vegetable material in fruit and vegetable processing plants, for the presence of alert pathogens of the ESKAPE group.

The study material consisted of water taken from five agri-food processing plants, in Poland. The raw material was washed with tap water, without disinfectant additives. Samples were taken in accordance with the Polish Standard (PN-EN ISO 19458:2007). After collection, the test material was transported to the laboratory. The methods used included classical microbiological analyses, using membrane filtration, as well as species identification, carried out using spectrometry with a MALDI Biotyper apparatus (Bruker, Germany) with CE and IVD certification (compliance with Directive 98/79/EC).

The results demonstrated a diverse contamination of the water with both environmental microorganisms and opportunistic pathogens. Among the ESKAPE bacteria, *E. coli*, *Klebsiella pneumoniae* and *Pseudomonas aeruginosa* were found. In addition, *Enterococcus facealis*, an indicator bacteria for water quality, was found in the water. The presence of these bacteria in the water suggests the possibility of contamination that may pose a risk to human health. Further research and action is needed to monitor and control water quality to prevent the spread of these pathogens and protect public health. The implementation of the circular economy in water reuse must be preceded by a microbiological analysis to identify potential risks and predict the performance of the water treatment process.

References:

Aivazidou, E., Tsolakis, N., Vlachos, D.P., Iakovou, E., 2017. Water Footprint Mitigation Strategies for Agrifood Products: The Application of System Dynamics in Green Marketing, in: Kavoura, A., Sakas, D.P., Tomaras, P. (Eds.), Strategic Innovative Marketing, Springer Proceedings in Business and Economics. Springer International Publishing, Cham, pp. 275–281. https://doi.org/10.1007/978-3-319-33865-1_35

Allende, A., Selma, M.V., López-Gálvez, F., Villaescusa, R., Gil, M.I., 2008. Impact of Wash Water Quality on Sensory and Microbial Quality, Including Escherichia coli Cross-Contamination, of Fresh-Cut Escarole. Journal of Food Protection 71, 2514–2518. https://doi.org/10.4315/0362-028X-71.12.2514

Gil, M.I., Selma, M.V., López-Gálvez, F., Allende, A., 2009. Fresh-cut product sanitation and wash water disinfection: Problems and solutions. International Journal of Food Microbiology, Food Micro 2008 "Evolving Microbial Food Safety and Quality" 1–4 September 2008, Aberdeen, Scotland, UK 134, 37–45. https://doi.org/10.1016/j.ijfoodmicro.2009.05.021

Jabbari Shiadeh, S.M., Pormohammad, A., Hashemi, A., Lak, P., 2019. Global prevalence of antibiotic resistance in blood-isolated Enterococcus faecalis and Enterococcus faecium: a systematic review and meta-analysis. Infect Drug Resist 12, 2713–2725. https://doi.org/10.2147/IDR.S206084

Jagtap, S., Skouteris, G., Choudhari, V., Rahimifard, S., 2022. Improving Water Efficiency in the Beverage Industry With the Internet of Things [WWW Document]. Implementing Data Analytics and Architectures for Next Generation Wireless Communications. https://doi.org/10.4018/978-1-7998-6988-7.ch002

Lapidot, A., Romling, U., Yaron, S., 2006. Biofilm formation and the survival of Salmonella Typhimurium on parsley. International Journal of Food Microbiology 109, 229–233. https://doi.org/10.1016/j.ijfoodmicro.2006.01.012

Lehto, M., Sipilä, I., Alakukku, L., Kymäläinen, H.-R., 2014. Water consumption and wastewaters in fresh-cut vegetable production. AFSci 23, 246–256. https://doi.org/10.23986/afsci.41306

Mritunjay, S.K., Kumar, V., 2017. A study on prevalence of microbial contamination on the surface of raw salad vegetables. 3 Biotech 7, 13. https://doi.org/10.1007/s13205-016-0585-5

Mundi, G.S., Zytner, R.G., Warriner, K., Gharabaghi, B., 2018. Predicting fruit and vegetable processing wash-water quality. Water Science and Technology 2017, 256–269. https://doi.org/10.2166/wst.2018.109

UN Water, 2018. Sustainable Development Goal 6: synthesis report 2018 on water and sanitation, United Nations publications. United Nations, New York, New York, United States of America.

Vanham, D., Alfieri, L., Flörke, M., Grimaldi, S., Lorini, V., de Roo, A., Feyen, L., 2021. The number of people exposed to water stress in relation to how much water is reserved for the environment: a global modelling study. The Lancet Planetary Health 5, e766–e774. https://doi.org/10.1016/S2542-5196(21)00234-5

Biological treatment of synthetic hypersaline wastewater: inoculum selection and start-up of a sequencing batch rector

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Keywords: hypersaline wastewater, halophile biomass, organic carbon removal

INTRODUCTION

At a global scale, it is estimated that approximately 5% of the influent that enters wastewater treatment plants is saline or hyper-saline and such percentage is expected to increase in the future (Cui et al., 2016). Some industrial sectors (agro-food, tanning, pharmaceutical, chemical) use salt in their production processes (Lefebvre and Moletta 2006). Other industries do not need salt, but operate in an environment where high salt concentration is or could be naturally present (aquaculture, desalinization, oil and gas) (Sahu 2021). Thus, a characteristic saline wastewater is generated depending on the industrial sector of origin. Domestic wastewater could acquire a high salinity due to seawater intrusion into the sewer system or when is used for domestic purposes, e.g. flushing toilets (Hülsen et al., 2019). Biological wastewater treatment is based on the metabolism of appropriate microbial consortia that degrades the pollutants of interest. High salt concentrations reduce the metabolic activity of microorganisms, thus affecting the treatment process (Ahmadi et al., 2017). Yang et al. (2013), reports that conventional microbial consortia cannot be used to treat wastewater with a salt concentration greater than 30 gNaCl/L. Biomass acclimatisation and adaptation can improve the performance of the treatment process compared to non-acclimatised biomass (Hülsen et al., 2019). Despite the increased salinity is tolerated, microorganisms are not effective in treating wastewater with salinities higher than 5% (Shi et al., 2012). In contrast halophilic microorganisms have specific salt requirements to growth and thrive so they could cope with salt (Yang et al. 2013). Even though it has been reported that biological processes can be adopted for the removal of organic compounds at 150 gNaCl/L (Kubo et. al 2001), a full assessment of the feasibility of using bio-treatment for high salinity wastewater is not available (Zhao et al. 2020).

Poor biomass sedimentation, turbidity of the effluent and reduced oxygen diffusion in the liquid medium have been reported as issues encountered when attempting to treat high salinity wastewater (Lefebvre and Moletta 2006).

This study is aimed at evaluating the applicability of samples of water and sediments collected from seawater evaporation ponds as inoculum for the biological treatment of hypersaline wastewater (110g NaCl/L) containing sodium acetate and yeast. Additionally, through the utilization of the next generation sequencing (NGS) analysis, a preliminary profile of microbial community was provided.

MATERIALS AND METHODS

Batch tests

Samples of sediments and water were collected from seawater evaporation ponds of Paceco, Trapani (Italy). The biological activity of the sediments was preliminarily evaluated by using the Oxitop system (WTW, Giessen, Germany), i.e. with a manometric monitoring device.

Four air-tight bottles (350ml working volume) were inoculated with 2 g of wet sediments, kept at 30±1°C and placed in an orbital shaker (140 rpm). Substrate impulsive injections (spikes) of rapidly biodegradable organic substrate (acetate and yeast) were provided every 2 to 4 days for 58 consecutive days and pressure variations recorded. Two salinities 100 gNaCl/L (salinity 1) and 140 gNaCl/L (salinity 2) were tested, both at aerobic and anaerobic conditions. Nutrients (N, P) and oxygen (for aerobic test) were provided at not

limiting concentrations. Before the beginning of anaerobic tests, nitrogen gas was sparged in the bottles' headspace in order to achieve anaerobic conditions.
COD concentration after substrate injection were set at 104, 384 and 335 mgCOD/L during days 1-43, 44-57 and 58-60, respectively. A CO_2 trap, containing NaOH pellets, was added in the headspace of aerobic bottles in order to record pressure variation only related to O_2 consumption.
Multiple injections were provided to evaluate the increase of the oxygen consumption rate or biogas production rate (methane and/or carbon dioxide) for aerobic and anaerobic tests, respectively.

Sequencing batch reactor
A 3.5L glass vessel reactor, equipped with mixing, aeration system and DO and temperature probe, was inoculated with 30g of sediments from the Trapani solar saltern. Influent and effluent pumps as well as aeration and mixing were controlled by a programmable logic control. A timer was utilised to regulate the aeration and the mechanical stirrer (maintained at 100-120 rpm). The reactor was operated in a sequence of phases: feeding (23 min), reaction (314 min), sedimentation (17-30 min) and discharge (15 min) for an overall cycle length of 6 hours. Hydraulic Retention Time (HRT) and Organic Loading Rate (OLR) were held constant at 1.2 days and 256±73 mgCOD/L*day respectively. In order to promote biomass enrichment, no sludge withdrawal was performed and sludge retention time was not actively controlled. The synthetic influent was prepared by adding yeast extract and sodium acetate as source of carbon and the following salts were added in the influent (per litre of solution): CH_3COONa 256.41 mg, Yeast 300 mg, NaCl 110 g, KCl 2 g, Mo 5 mg, N-NH_4^+ 50 mg, P-PO_4^{3-} 10 mg. COD influent and effluent analysis, were performed through cuvette test kits (LKC 1814 Hach Lange) designed for high salinity (1-20 gCl^-/L).
On average, 1-2 samples per week were analysed, when possible.

A biomass sample was withdrawn on day 86 in order to perform microbial community analysis. Biomass sample was taken from the vertical midpoint of the reactor during the last hour of the reaction phase. Samples were stored at -20 °C before processing. DNA was extracted with DNeasy PowerSoil Pro kit Qiagen (Germany). A PCR analysis on the conserved V3-V4 regions of 16S ribosomal RNA (rRNA) was carried out. The amplicons were sequenced using Illumina MiSeq technology at BMR Genomics srl (Padua, Italy). The data generated in the FastQ format was processed with the R program with the use of specific packages (DESeq2, phyloseq, ggplot2, vegan).

RESULTS AND DISCUSSION
The graph on the left of figure 1 illustrates the oxygen consumption rate of the tests under aerobic conditions (at salinity 1 and at salinity 2) over a period of 58 days.
The rate of oxygen consumption increased significantly after the first 44 days, from an average of 0.57 mg O_2/h to 2.45 mg O_2/h and from 0.42 mgO_2/h to 1.92 mgO_2/h for the salinity 1 and salinity 2, respectively.

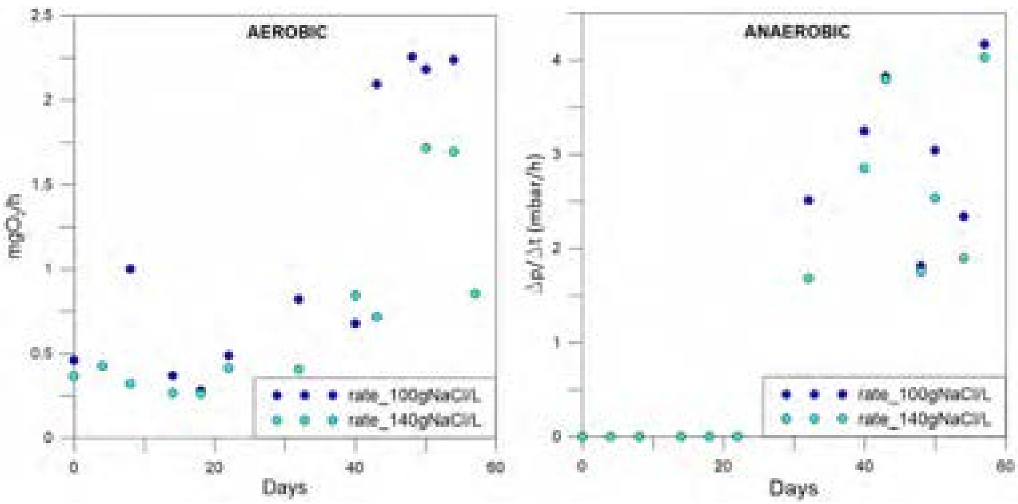

Figure 4 Maximum oxygen consumption rate (left) and biogas production rate (right) in batch tests.

A rapid rise of microbial activity was seen when the organic substrate concentration was raised from 104 up to 384 mgCOD/L respectively on the 44th experimental day.
As a general behavior, oxygen consumption rates for the test with salinity 2 were lower than the ones for the test with salinity 1. The oxygen consumption rate values in salinity 2, during the initial phase of the examination that lasted from day 1 to 44 and had a lower substrate input, were on average 26% lower than in the salinity 1 test. The oxygen consumption rates in the salinity 2 test, subsequent to the increase in substrate supplied (after day 44), are 22% lower than those recorded in the salinity 1 test.
As shown in Figure 1, the right graph indicates that there was no evidence of biogas production during the initial month of the experiment. After growth and reactivation of the anaerobic biomass, an average biogas production determining pressure increase rate of 3.3 mbar/h was observed for the salinity 1 anaerobic test and 2.8 mbar/h for the salinity 2 anaerobic test.
Regarding the operation of the SBR reactor, saline sediments were chosen as the inoculum source for the SBR reactor because of their positive response to organic substrates removal in aerobic condition. After a period of approximately four months, the biomass showed high organic carbon removal (78±9%) in hypersaline wastewater at 110 gNaCl/L (see left figure 2).
Moreover, Figure 2 illustrates the microbial community characterization on day 86, with *Halomonas* as the most abundant genus (a relative abundance of no less than 35%).

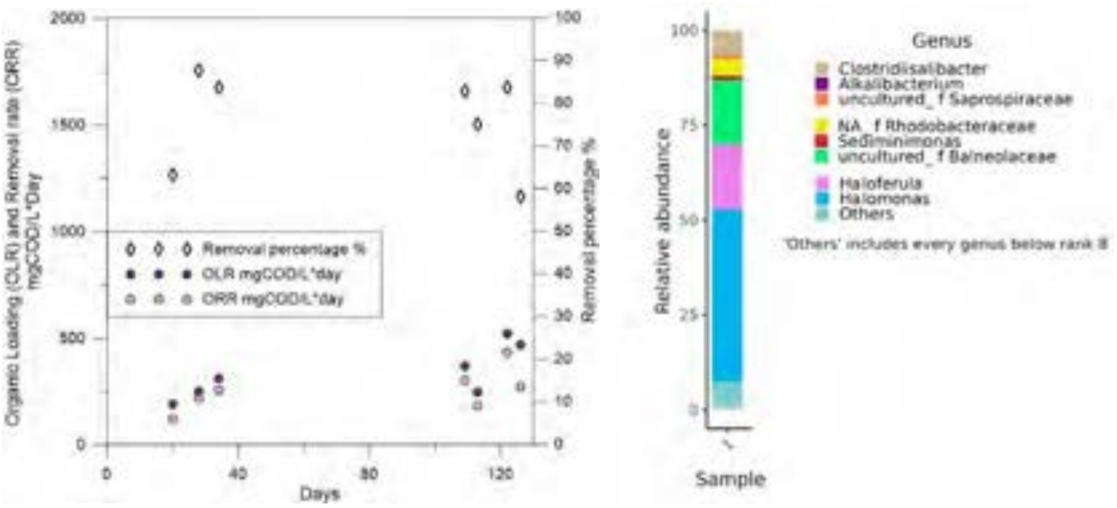

Figure 5 Organic Loading and removal rate (OLR,ORR) and efficiency of the process (left) and microbial community structure (right).

The biomass displayed good settling capacity, as evidenced by the formation of a clearly visible sludge bed within 15 minutes. The use of an optical microscope was employed to observe the sludge collected from the reactor after 73 days of experimentation. The right part of figure 3 illustrates a large and well-aggregated floc.

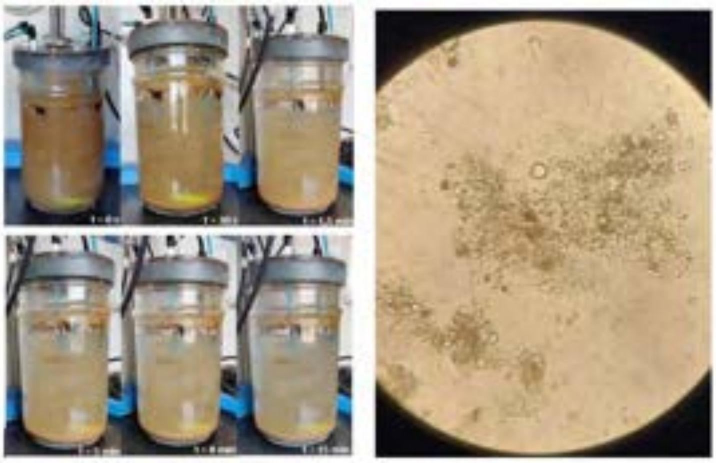

Figure 6 Settling biomass performance on SBR (left) and sludge structure (x100 biomagnification) (right).

However, it has been reported in the literature that sludge structure and its settling capacity are negatively affected by high salinity (>1 wt%) (He et al., 2016).
This study presents results on the potential of biological treatment of hypersaline wastewater, after inoculum selection and enrichment, studied both under batch and continuous operation. It is believed that these evidences are a relevant contribution for the future application of halophilic biomass for wastewater treatment in the agro-food and oil/gas extraction sectors.

Acknowledgements
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References:

Ahmadi M, Jorfi S, Kujlu R, Ghafari S, Darvishi Cheshmeh Soltani R, Jaafarzadeh Haghighifard N. A novel salt-tolerant bacterial consortium for biodegradation of saline and recalcitrant petrochemical wastewater. J Environ Manage. 2017 Apr 15;191:198-208. doi: 10.1016/j.jenvman.2017.01.010.

Cui, Y. W., Zhang, H. Y., Ding, J. R., & Peng, Y. Z. (2016). The effects of salinity on nitrification using halophilic nitrifiers in a Sequencing Batch Reactor treating hypersaline wastewater. *Scientific reports*, *6*, 24825. https://doi.org/10.1038/srep24825.

He H., Chen Y., Xiang Li, Cheng Y., Yang C., Zeng G., Influence of salinity on microorganisms in activated sludge processes: A review, International Biodeterioration & Biodegradation, 119, 2017, 520-527, ISSN 0964-8305, doi: 10.1016/j.ibiod.2016.10.007.

Hülsen T, Hsieh K, Batstone DJ. Saline wastewater treatment with purple phototrophic bacteria. Water Res. 2019 Sep 1;160:259-267. doi: 10.1016/j.watres.2019.05.060.

Kubo M, Hiroe J, Murakami M, Fukami H, Tachiki T. Treatment of hypersaline-containing wastewater with salt-tolerant microorganisms. J Biosci Bioeng. 2001;91(2):222-4. doi: 10.1263/jbb.91.222.

Lefebvre O, Moletta R. Treatment of organic pollution in industrial saline wastewater: a literature review. Water Res. 2006 Dec;40(20):3671-82. doi: 10.1016/j.watres.2006.08.027.

Sahu P. A comprehensive review of saline effluent disposal and treatment: conventional practices, emerging technologies, and future potential. *Water Reuse* 1 March 2021; 11 (1): 33–65. doi: https://doi.org/10.2166/wrd.2020.065.

Shi X., Lefebvre O., Ng K.K., Ng HY. Sequential anaerobic-aerobic treatment of pharmaceutical wastewater with high salinity. Bioresour Technol. 2014 Feb;153:79-86. doi: 10.1016/j.biortech.2013.11.045.

Yang J., Spanjers H., Jeison D., Van Lier J.B. (2013) Impact of Na+ on Biological Wastewater Treatment and the Potential of Anaerobic Membrane Bioreactors: A Review, Critical Reviews in Environmental Science and Technology, 43:24, 2722-2746, doi: 10.1080/10643389.2012.694335.

Zhao Y, Zhuang X, Ahmad S, et al. Biotreatment of high-salinity wastewater: current methods and future directions. World J Microbiol Biotechnol. (2020) Feb 22;36(3):37
doi: 10.1007/s11274-020-02815-4.

Innovative hybrid dairy wastewater system assisted by an intelligent software tool for quality prediction of the processed product water to be used for crop irrigation in a greenhouse.

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Keywords: Hybrid System, electrocoagulation, dairy wastewater treatment, industrial research, greenhouse

ABSTRACT

The rapid increase in industrial activity and the overconsumption of goods, has led to environmental degradation caused by the discharge of untreated wastewater. The introduction of strict laws and restrictions in the industrial sector, in combination with environmental awareness makes water treatment an inevitable requirement for sustainability.

This work focuses on the design, construction, implementation and demonstration of an advanced automated, energy efficient, environmentally friendly, hybrid waste treatment system in a pilot - lab scale dairy processing unit, with the aim of maximizing the recovery of clean water for subsequence use in agriculture. In addition, the process supports the recovery of useful by-products to be used as fertilizers. The work also includes integration of a smart information tool for the wastewater treatment system, for product water quality monitoring and prediction. The final product of the system is high-efficient 'clean' water to be used for irrigation through the construction of a pipeline from the industrial unit to the greenhouse. The hybrid character of the system (combination of processing technologies) and the advanced design of the electrocoagulation reactor are system's innovations. In addition, as the last filtering process of the water product, a biological purification will take place where the treated water will pass through a reed plantation.

Finally, the treated–clean water is supposed to contain a certain concentration of trace elements, (to be determined). By adding mineral salts to the treated water an ideal nutrient solution for soilless cultivation of plants will be produced which will be tested for irrigation of a lettuce plantation in an experimental greenhouse.

The experimental results of the implementation of the proposed wastewater system will be presented and also the results of applying the processed water for crop irrigation in the greenhouse will also be discussed.

Acknowledgements

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Session B12: Ecological engineering for the protection of land and biodiversity

Integrating the scope of ecological engineering applications: A structured framework with case studies from Australia

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Keywords: Ecological engineering applications; nature-based solutions; performance-based design, sustainable development

ABSTRACT

Ecological engineering has a critical role to play in addressing one of society's grandest challenges of working out how people and nature can beneficially coexist on planet Earth.
However, 61 years after the term was coined by Howard Odum (Odum, 1962), ecological engineering remains a relatively niche and under-recognised discipline. Notwithstanding, the related concept of Nature Based Solutions is gaining worldwide recognition and momentum (Kalantari *et al*., 2023) although adherents may implement, but not identify with the performance-based design approach inherent to ecological engineering.
It is postulated that, by its nature, application areas of ecological engineering are so wide and varied that the discipline lacks the concentration of other engineering disciplines and, hence, mainstream recognition. It is further suggested that practice is leading theory, and that ecological engineering solutions are more widely implemented than might be indicated by membership of professional associations or formal courses.
Around the globe, the focus of ecological engineering applications displays regional variation, but a cursory review of journals and courses indicates a strong focus on the discipline's origins in treatment wetlands and ecosystem restoration.
A structured framework for the integration of ecological engineering applications across a spectrum from production to rehabilitation is proposed:

- Sustainable production;
- Sustainable construction;
- Reduction (of impact intensity);
- Prevention (of pollution and degradation);
- Recycling; and
- Rehabilitation.

Case studies from Australia of applications across this framework are presented as a means to broaden recognition of the discipline, the important role it has to play in supporting sustainable development and encouraging wider recognition among the community of practice and academia.
Sustainable production: The key land-based impacts to the health of the Great Barrier Reef are dissolved inorganic nitrogen, fine sediment and pesticides (Brodie *et al*., 2013). Extensive grazing across the Fitzroy Basin in Queensland, an area of 143,000km^2, is estimated to generate around 390kt/yr of anthropogenic fine sediment (Australian Government, 2018). Quantitative monitoring and modelling of ground cover condition using the dynamic reference cover method (Bastin *et al*.2012), to support improved grazing practice and a provide a market mechanism for ecosystem services (Silverwood *et al*., 2023) is aimed at providing a business case to improve grazing production and reduce fine sediment loads to protect reef health.
Sustainable construction: Typically considered in the context of green urban infrastructure, sustainable construction may also apply to large industrial developments. Extraction of coal seam gas for use as a transition fuel between coal and renewables necessarily involves coextraction of mildly saline and highly sodic water. The conventional engineering approach to management of this water involves construction of capital intensive, high-energy demand desalination facilities. Salt extracted in these facilities is disposed

in landfill. An alternative ecological engineering approach involved thermodynamic modelling and empirical soil threshold electrolyte conductivity testing to understand the interaction of water chemistry with soil physico chemical properties. This enabled the design of a 10ML/day chemical water treatment plant to produce agricultural grade water for irrigation of 1100ha of forest plantation, with no waste (Dale *et al*, 2013).

Reduction (of impact intensity): Energy saving technologies, biofuels and bio-sequestration all contribute to reduction of impact intensity. In addition to supporting sustainable construction, the forest plantation described in Dale *et al.* (2013), has also been registered as a carbon sequestration planation under Australia's Emissions Reduction Fund. At age 14, the plantation has removed 76 t CO_2e/ha of legacy carbon from the atmosphere. Although a small contribution to global reduction of atmospheric greenhouse gasses, expansion of new plantations may contribute to slowing the rate of CO_2 rise and, if managed on a rotational basis, will create long-term carbon stores in wood products and displace emissions-intensive building products such as concrete and steel.

Prevention (of pollution and degradation): Sewage treatment plants are conventionally designed to treat influent water to licenced residual and nutrient levels prior to discharge to waterways. As populations grow, cumulative catchment loads may increase, threatening surface water quality and aquatic habitats. The Maleny Irrigated Forest and Wetland (Dale and Mills, 2014) was designed to beneficially use effluent water and provide final-stage nutrient removal from the Maleny sewage treatment plant (STP). The STP treats sewage water to A Grade via a membrane bioreactor process prior to irrigation to a constructed rainforest, and filtration through a constructed wetland. The 19ha forest and associated wetland is designed to treat up to 925kL of effluent per day. The forest also provides a recreational resource for the local community and is commonly used for bush walking and bird watching. In ten years of operation, the forest has delivered greater nutrient removal efficiency with higher reliability and substantially lower cost than conventional grey infrastructure.

Recycling: Biosolids: Annual global fertiliser demand for 2022 is estimated in the order of 111 million t of nitrogen, 49 million t of phosphorous, and 40 million t of Potassium (FAO, 2019). These nutrients are manufactured from non-renewable natural gas (nitrogen) or mined from finite concentrated deposits (phosphorous and potassium). Nutrients used in agriculture are concentrated in food and partially captured in sewage sludge. Beneficial use of sewage biosolids (treated sewage sludge), managed under strictly regulated procedures as an organic fertiliser and soil amendment is contributing to the circular economy by recycling the embodied nutrients. In addition, biosolids increase soil carbon and health (Snyder, 2021), displace mineral fertilisers and deliver significantly improved crop yields. In 2023, Verterra commenced the world's first project to sequester soil carbon through beneficial use of biosolids under a regulated carbon scheme.

Rehabilitation: Erosion from alluvial gullies in sodic soils deliver approximately half the fine sediment exported to the Great Barrier Reef from land-based activities, posing a serious threat to the health of coral and seagrass habitats, and reducing their ability to withstand or recover from events like coral bleaching. Alluvial gully erosion is a complex process, often initiated in the 1940s and 1950s, and once started, continues at a rate and scale beyond the capability of private landholders to address from both a technical and financial view. Repair of alluvial gullies delivers a minor private benefit and large public benefit. Through the NQ Dry Tropics' "Landholders Driving Change Project", a toolkit of approaches to repair alluvial gully erosion and re-establish a self-sustaining, functional ecosystem has been developed. Predictable, performance-based restoration outcomes have been achieved by adapting a complex approach to Bayesian modelling of residual erosion risk in rehabilitated mine lands (Dale *et al*, 2018; Dale *et al*., 2022).

References

Australian Government (2018). Reef 2050 Water Quality Improvement Plan 2017–2022. 56pp.

Bastin G, Scarth P, Chewings V, Sparrow A, Denham R, Schmidt M, O'Reagain P, Shepherd R & Abbott B (2012). Separating grazing and rainfall effects at regional scale using remote sensing imagery: A dynamic reference-cover method. Remote Sensing of Environment, 121, (2012), 443-457.

Brodie, J. et al., (2013). Scientific Consensus Statement. Chapter 3: Relative risks to the Great Barrier Reef from degraded water quality The State of Queensland.

Dale, G. T., McCallum, L., Silverwood, B., Bingham, C., Bennett, JMcL., Ghahramani, A., Ali, A. and Roberton, S.D. (2022). "User driven refinement of decision support tools to inform final mined landform outcomes". ACARP Project Report C28044. 294 pp. + Appendices.

Dale, G,T. and Mills, A. (2014). Ecological Engineering - Maleny Effluent Irrigated Rainforest and Wetland. *Presentation to the:* Irrigation Australia Conference, 2-6 June 2014, Gold Coast, Queensland.

Dale, G.T., Robb, I., Halpin, N., D. Macfarlane, D. and Rattray, R. (2013). Opportunities for integrated mine management to minimise risk and create value. In: Proceedings Water in Mining 2013, pp 227-234 (The Australasian Institute of Mining and Metallurgy: Melbourne).

Dale, G. T., Thomas, E., McCallum, L., Reardon-Smith, K., Bennett, J. and Raine, S. (2018). "Applying risk-based principles of dispersive mine spoil behaviour to facilitate development of cost-effective best management practices". ACARP Project Report C24033. 194 pp. + Appendices.

FAO (2019). World fertilizer trends and outlook to 2022. Rome. https://www.fao.org/3/ca6746en/CA6746EN.pdf

Kalantari, Z., Santos Ferreira, C.S., Pan, H., an Pereira, P. (2023). Nature-based solutions to global environmental challenges. Science of The Total Environment, Volume 880, 1 July 2023, 163227. https://doi.org/10.1016/j.scitotenv.2023.163227.

Odum, H.T. (1962). "Man and Ecosystem" Proceedings, Lockwood Conference on the Suburban Forest and Ecology. Bulletin Connecticut Agric. Station.

Silverwood, B., Yates, A., Costin, A., Dr Dale, G., Waterson, D., Sweetman, C., Berwick, M., Shoo, L., Warnken, M., Ash, R., Bremner, A., Addinsall, M. (2023). Reef Credit method for accounting fine sediment abatement through improved grazing land management. 26pp. In review.

Snyder, A. (2021). Stability of biosolids derived carbon in soils; evidence from a long-term experiment and meta-analysis. Master of Science, Ohio State University, 126pp.

Field application of processed biosolids: Integrating municipal waste management and regenerative agriculture in Canada

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ABSTRACT

More than a 750 dry kt of sewage sludge are produced annually in Canada. Instead of landfilling or incinerating the sludge, it is increasingly processed into biosolids and applied to agricultural fields as organic fertilizer. We often assume that the greenhouse gas emissions (GHGs) resulting from this practice are net-negative, but this has not been well studied. To help address this research gap, we conducted field experiments at sites in Truro (Nova Scotia), Montreal (Quebec), and Edmonton (Alberta). Sewage sludge was either anaerobically digested, composted, or alkaline stabilized. At each site, we applied the resulting biosolids alone or in combination with chemical fertilizer at rates commensurate with the nutrient requirements of the crop, according to a randomized complete block design with positive and negative controls. We measured GHGs (CO_2, CH_4, and N_2O) from the field with both automated and manual flux chambers and performed a carbon-footprint analysis to estimate related upstream GHGs. Soil and crop characteristics were measured to quantify agronomic impacts. Crop production was equivalent for all treatments except the negative (zero fertilizer) controls ($P<0.05$). Field emissions of GHGs were greatest from plots fertilized with digested biosolids ($P<0.05$). The plots amended with composted biosolids had the largest overall carbon footprint, including upstream GHGs, because of the large amount of material processed to supply the crop nitrogen requirements. These results provide region-specific data about GHGs from field-applied biosolids and will help improve Canada's national GHG inventory as reported to the Intergovernmental Panel on Climate Change.

Innovative bioinspired intervention to control the growth of a new spit and reduce the occlusion of the mouth of the Goro lagoon (Italy)

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Keywords: Spit evolution, coastal geomorphology, bioinspired solutions, delta Po (Italy)

ABSTRACT

Coastal lagoons are estimated to occupy 13% of the world's coastline (Barnes, 1980), and Bird (1994) defined coastal lagoons as areas of relatively shallow water that have been partly or wholly sealed off from the sea by the formation of depositional barriers, usually of sand or shingle, built up above high tide level by wave action. Their formation and development are linked to the coastal barriers or spit, which may be characterized by fragmentation processes that affects their natural function of protecting the lagoon against waves. Today it is well recognized that human influences play a key role in their evolution and development, and as mentioned by Davies-Vollum et al. (2019) the complex interplay of physical and human variables influences the geomorphology of barriers and the incidence of tidal inlets (lagoon openings).

Our study focus on the spit of Goro, located in the right side of the Goro Po mouth, northern Adriatic (Italy), formed during the 19th century with the formation and development of a spit system (Simeoni et al, 2000). Geomorphological evidences, historical maps and aerial photos show how the spit has always been characterized by rapid evolutionary dynamics. The spit of Goro, affected by fragmentation due to wave's actions and subsidence, has been repeatedly dismantled and reconstructed at intervals that can be estimated around 10-20 years (Simeoni et al., 2007).

Between the years '40 and '80s, the wave action prevailed and a regressive phase of the spit began inducing a fan-like growth style: same origin but with radial translations of the directions of the growth axis. In particular, since the 1980's the spit is characterized by a branched growth (Simeoni et al., 2007) where the origin of new ramifications no longer coincides with the area of the mouth, but it is transferred downdrift. Their development is significantly supported, especially in the central and terminal sections of the spit, by the formation of small spit ramifications. The international literature reports cases in which these ramifications can grow to become a real littoral spit (Elfrink et al., 2003).

To slow the occlusion of the lagoon mouth and protect a coastal stretch spit from erosion, a bioinspired experimental intervention, through an interdisciplinary approach, was carried out as part of the Life + project "Life Agree", which aimed to control the growth of a new ramification of the spit, thus reducing the deposition of sediment in the lagoon mouth and protecting the coastal stretch in erosion. It consists in a semi-impermeable wooden groin that should favor the spit formation by controlling its direction rather than stop the sand transport (figure 1).

The design started from the analysis of the development of new spits (germination) on satellite images and Lidar surveys from 2001 to 2017, in order to better understand their position, shape and direction of growth. Thus 200 spits were identified. The results highlight that the spits initially growth seaward, and successively flex and rotate landward until they coalesce with t the beach. In addition, they generally reach an average length of 72 m (max 373 m, min 12 m), an average width of the emerged part of 16 m (max 91 m, min 2m) and an average angle between the shoreline and the spit of 16° (from 2°N to 91°N).

After three years, it has been observed a positive impact on the intervention area, favouring the growth of two sandbanks which represent the initial phase of a new possible gemination. The analysis of the evolution of bathymetric profiles also indicate the formation of two sandy accumulations at 50 and 250 m from the shore. It is important to mention that the development of these morphologies requires relatively long times and consequently need careful studies and monitoring.

Figure 1: Bioinspired solution realized along the spit of Goro, Italy (left: July 2018, right: June 2019)

The results obtained demonstrated that observation of natural systems, such as functional strategies, adaptability, and regeneration can guide coastal design projects towards new sustainability scenarios with a real connection to the natural world, as mentioned by Perricone et al. (2023).

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References:

Barnes, R. S. K., 1980. Coastal Lagoons. Cambridge: Cambridge University Press.

Bird, E. C. F. 1994. Chapter 2 Physical Setting and Geomorphology of Coastal Lagoons. Elsevier Oceanography Series, 9–39. doi:10.1016/s0422-9894(08)70007-2

Davies-Vollum, K.S., Zhang, Z. & Agyekumhene, A., 2019. Impacts of lagoon opening and implications for coastal management: case study from Muni-Pomadze lagoon, Ghana. J Coast Conserv 23, 293–301, https://doi.org/10.1007/s11852-018-0658-1

Elfrink B., Prestedge G., Rocha C. B. M., and Juhl J. 2003. Shoreline evolution due to highly oblique incident waves at Walvis bay, Namibia. Coastal Sediments 2003

Perricone, V., Mutalipassi, M., Mele, A., Buono, M., Vicinanza, D., Contestabile, P., 2023. Nature-based and bioinspired solutions for coastal protection: an overview among key ecosystems and a promising pathway for new functional and sustainable designs, ICES Journal of Marine Science, 1–22, DOI: 10.1093/icesjms/fsad080

Simeoni, U., Dal Cin, R., Fontolan, G., Tessari, U., 2000. Morfogenesi ed evoluzione dello Scanno di Goro (Delta del Po), Studi Costieri (2), 5-20

Simeoni, U., Fontolan, G., Tessari, U., Corbau, C., 2007. Domains of spit evolution in the Goro area, Po Delta, Italy, Geomorphology, 86, 332-348, https://doi.org/10.1016/j.geomorph.2006.09.006

Modification of spent coffee grounds for their use as organic fertilizer

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Keywords: spent coffee grounds, organic fertilizer, lactuca sativa, phytotoxicity, C/N ratio

ABSTRACT

Due to the growing population and consequent pressure of use, agricultural soils must maintain adequate levels of quantity and quality to produce food, fiber, and energy. The use of mineral fertilizers has long been a key tool to offset nutrient outputs and thus achieve increased yields. On the other hand, improper fertilizing technology might have a negative effect on soil health and soil-related ecosystem services (Krasilnikov et al.. 2022). This calls for the need to recycle various types of biomass waste such as animal manure, sewage sludge waste, and food waste into organic fertilizers. Global food waste production exceeds 1300 million tons. One of the important food wastes is wheat bran and spent coffee beans. World production of wheat bran reaches 100 million tons per year and spent coffee grounds about 6 million tons per year. However, these wastes are currently minimally used in the circular economy concept and their fate ends in incinerators or on landfills.

There are different opinions in the literature on the application of spent coffee beans in agriculture for the purpose of fertilization and improvement of soil quality. While one opinion highlights the positive properties of the spent coffee grounds, opponents often argue the phytotoxic effects of substances found in the spent coffee grounds. It was previously reported that the addition of 2,5 % of spent coffee grounds to the soil had a significant negative effect on plants (Cruz et al., 2015; Ciesielczuk et al., 2018).

The presented study deals with the possibilities of detoxification of used coffee beans and the possibilities of using this material in combination with wheat bran and biochar from wheat bran as an organic fertilizer. The prepared organic fertilizer was applied to selected soil types and growth experiments were conducted with lettuce (*Lactuca sativa L.*) to verify the effectiveness of this fertilizer. The results of present work demonstrated the improvement of some parameters of the soils used. However, despite a significant reduction in the content of phenolic substances and caffeine in spent coffee grounds applied to the soil in the form of organic fertilizer, a negative influence on lettuce growth was observed. The negative effect on lettuce growth was probably caused by an increase in the carbon content of the soil, thereby increasing the C/N ratio in the soil. Obtained results indicate that the prepared organic fertilizer must be further enriched with the addition of a nitrogen source if it is to be effectively used in agriculture.

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References:

Krasilnikov, P., Taboada, M.A., Amanullah, 2022. Fertilizer Use, Soil Health and Agricultural Sustainability. *Agriculture 12 (4)*, 462, https://doi.org/10.3390/agriculture12040462

CRUZ, R., MENDES, E., TORRINHA, A., MORAIS, S., PEREIRA, J.A., BAPTISTA, P. and CASAL, S., 2015. Revalorization of spent coffee residues by a direct agronomic approach. Food Research International 73, 190–196. https://doi.org/10.1016/j.foodres.2014.11.018

CIESIELCZUK, T., ROSIK-DULEWSKA, C., PLUSZYŃSKA, J., MIŁEK, D., SZEWCZYK, A. and SŁAWIŃSKA, I., 2018. Acute Toxicity of Experimental Fertilizers Made of Spent Coffee Grounds. Waste and Biomass Valorization 9(11), 2157–2164. https://doi.org/10.1007/s12649-017-9980-3

Nature-based solutions using ecological engineering and dedicated to combine the mitigation of natural risks linked to water with benefits for biodiversity: considering interdisciplinary and transdisciplinary approaches

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Keywords: Nature-based solutions; Ecological engineering; Natural risks; Ecological restoration

ABSTRACT

Ecological engineering (EE) meets Nature-based solutions (NbS) with common principles and objectives. They both respond to current challenges for environmental management, as considering co-benefits approaches. However numerous barriers exist for the implementation of NbS using Ecological engineering, the latter mentioning very often the significance of the ecology discipline. Focusing on the social challenge of preventing natural risks linked to water, we highlight the importance of considering interdisciplinary and transdisciplinary approaches in projects trying to reconcile flood mitigation with benefits for biodiversity. This calls for new approaches in research, practice and governance. It allows identifying levers for better promoting the use of NbS using EE for this kind of application but also for other social issues.

Introduction: what is a nature-based solution using ecological engineering?

Nature-based solutions (NbS) offer a way to preserve, manage and restore ecosystems to meet today's societal challenges by combining benefits for society and biodiversity. They incorporate natural features and processes into projects to ensure their sustainable development while investing in the preservation, restoration and management of ecosystems. They are a recent policy tool used to both answer social issues and preserve biodiversity. This concept has been defined at a global scale by institutions such as the European Commission or the International Union for the Conservation of Nature (IUCN). Nowadays, many countries have adopted it and are implementing NbS projects (Cohen-Shacham et al., 2019).

NbS call for methods and techniques in Ecological engineering (EE). This term has been proposed by Odum at the beginning of the 60's, as "the management of nature" (Odum, 1963). Later, Mitsch and Jorgensen (2003) largely worked on this concept and finally defined it as "the design of sustainable systems, consistent with ecological principles, which integrate human society with its natural environment for the benefit of both". Bergen et al. (2001) insist as for them on the need for EE practices to be based on the science of ecology. They also precise that all types of ecosystems and interactions between man and nature are concerned. It is also possible to enter it upon two different viewpoints, one theoretical and the other applied (Gosselin, 2008). EE can thus be considered as all the strategies, tools and techniques brought together for action, as a product of the "translation" of the results of ecological research applied to projects. EE, such as Soil and water bioengineering (SWB), appears as the best tool to implement NbS projects (Preti et al., 2022).

Nature-based solutions to combine the mitigation of natural risks linked to water with benefits for biodiversity

NbS can be applied in many ways in the field of water management, from protecting the quality and quantity of water resources to reducing natural hazards (floods and droughts) while preserving biodiversity (Figure 1). For example, facing an increase in the frequency and intensity of severe rainfall events due to climate change, we can mention wetlands as flood expansion zones: they combine the protection of people and property with gains for biodiversity. Another example is the restoration of a stream through meanders, which allows it to function more naturally, while slowing the water speed and its impact on flooding. Nature in the city enables mitigating runoff while improving biodiversity. Lastly, we can also consider the vegetalization of civil engineering structures on riverbanks (Rey, 2021). NbS can be seen as an innovative way of overcoming the classical opposition between flood risk protection versus ecological preservation. If implemented with full consideration of the local context, they could prompt positive changes, helping to reframe policy debates about climate change adaptation, increasing the participation of citizens into risk management policy and planning, while reconciling risk mitigation and biodiversity conservation strategies under a common framework.

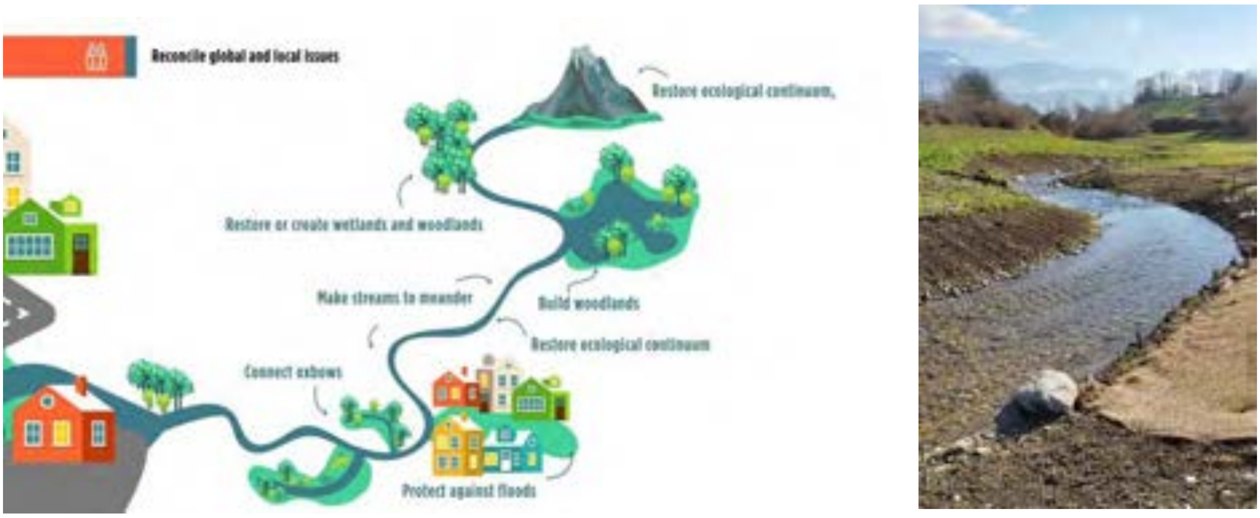

Figure 1: NbS for preventing and mitigating water-related natural hazards

However, numerous barriers exist for the implementation of NbS using EE. Indeed, a lack of appropriation of the concept by local stakeholders or unsuitability to local contexts could lead to adverse effects. While NbS have been embraced on an international scale, they are implemented in very different local contexts, and we know still little about how it is actually implemented on the ground. Governments worldwide are now investing in so-called NbS projects to address challenges in sustainable management of water-related risks and biodiversity conservation, restoration or management. But up to now, much of the research on NbS has focused on: i) its definition at a global scale, scholars acknowledging its lack of clarity and its Eurocentric focus; ii) its implementation in isolated case studies. Little is known about how NbS are understood and handled in different institutional, geographic and socio-political contexts, implemented by actors with different and often conflicting goals, values, representations, sources of legitimacy and power. This is however a crucial issue since it impacts how social and ecological benefits will actually materialize and be shared within societies.

To fill this gap, focusing on the social challenge of preventing natural risks linked to water, we consider of prime importance to consider interdisciplinary and transdisciplinary approaches in projects trying to reconcile flood mitigation with benefits for biodiversity. This should allow identifying barriers and levers for better promoting the use of NbS using EE for this kind of application.

Considering interdisciplinary approaches

The development of NbS actions requires interdisciplinary approaches to design effective and sustainable projects. For the most part, work on EE and ecosystem services has been developed in the field of ecology (Bergen et al., 2001). Their application to water environments also called for investigations in the field of geosciences and especially in hydrology and hydrogeology, and applied to eco-hydrosystems. The research results should allow improving the resilience of ecosystems, as well as territories, and to prevent natural risks by better taking into account the functions offered by water ecosystems in the sustainable development and planning strategies of these territories (Rey, 2021).

It is also necessary to seek to understand the double ecological and social dimensions of the management of biodiversity, within socio-ecological systems to study. Questions on the rise of the concept of NbS, its origin, its appropriation, its implementation, its development modalities and its consequences on the relationship of Man to Nature within socio-ecosystems have to be addressed. The purpose of current and future research in these domains is to contribute to better conduct and support organizations for and in the implementation of NbS, by integrating the contours and the meanings of this concept, in relation to research and management practices that may or may not rely on it. Furthermore, such an integrated approach needs to consider not only environmental and social aspects, but also economic ones.

Thirdly, political approaches are fundamental to achieve the real applications of NbS given the prominence of institutional barriers (Nesshöver et al., 2017). The use of EE to implement NbS does not only represent a technical evolution but can be considered as a paradigm shift that profoundly transforms the way environment is managed (Moreau et al., 2022). This would involve conducting research on the analysis of stakeholder systems and on the governance modalities of NbS, with a view to improving the resilience of the territories to the challenges of climate change. This would include a better understanding of institutional changes (imposed, wanted or potential) in organisations (local authorities, socio-professional and inter-professional organisations, etc.) that seek (or wish to seek) implementing NbS that must (or will) adapt to resource management constraints, as well as the territorial and participatory governance imposed by public policies.

Transdisciplinary approaches for better combining flood mitigation with benefits for biodiversity

Transdisciplinary approaches should also allow proposing dedicated frameworks for the application of NbS. They necessitate considering engineering and research, with collective research practice including actors of society for a connection and integration of knowledge.

A challenge is to characterize or evaluate the governance modes associated with NbS for water-related issues, particularly flooding by overflow and runoff, but also the sustainable management of water resources in a changing climate. This would involve answering the following questions: what type of governance is preferred, or should be sought, in the implementation of the NbS? What are the levers or obstacles presented by them? Although considering the design of NbS dedicated to natural hazards linked to water at the catchment scale appears to be the coherent scaling approach, political decisions are in general taken at the mono-scale of administrative areas, which do not necessarily correspond to the catchment limits. A change between the two approaches can cause problems in applying the most suitable NbS for flood prevention and biodiversity restoration. This is why it is necessary to define a specific governance dedicated to the application of this type of NbS at the catchment scale, through interdisciplinarity (geosciences, ecology, political and social sciences) and transdisciplinarity (researchers, engineers and policy makers) (Young et al., 2019).

The good application of NbS requires adapted governance but also specific policy (Cohen-Shacham et al., 2019). How are NbS integrated into local public policies? Do NbS make it possible to effectively rework the relationship between environmental conservation policies (and operational departments) and the ones dedicated to water-related risks or the sustainable management of water resources? For this, an analysis of the actor's land system linked to catchments where flood prevention and biodiversity restoration are considered, should be carried out. It corresponds to the actors and their decision factors, as well as to the governance modalities of the NbS, by crossing the considerations at the level of the catchment (scale of application of the NbS to prevent floods and restore biodiversity, through ecological measures) and at the administrative or project level (decision scale).

Concerning management and recommendations, what are the implications of civil society / private actors / local authorities? What methods of financing investments and operations should be adopted? A stronger decision-making system should ensure that the solutions proposed are feasible and that all the objectives of co-benefits projects are compatible. It should facilitate the overcoming of various objectives such as the reduction of damage and the preservation of biodiversity, that require multi-criteria analyses to address the key challenge of integrating aquatic management and flood prevention. An expected outcome could be to enable practitioners and engineers to find truly integrated NbS to reconcile flood prevention and biodiversity benefits across the catchment and the territory. They could take the form of recommendations for defining long-term maintenance of NBS, improving territorial organisation, providing increasing resilience to flooding and more broadly to natural hazards related to water (erosion, runoff, floods, drought), improving multi-stakeholders participation, and combining city and inter-city (community) management (Lupp et al., 2021).

Conclusion

These reflexions could be sources of further disciplinary, interdisciplinary and transdisciplinary research since they combine approaches in several scientific disciplines, and involve different kinds of actors. NbS, seen as multi-benefits actions, may allow for more integrated management of natural and local natural risks, and in particular to ally flood prevention with aquatic environment management. However, this kind of approach calls for new, much more global research, whose results should become the knowledge base of engineers, managers, and decision-makers.

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References:

BERGEN, S.D., BOLTON, S.M., FRIDLEY, J.L., 2001. Design principles for ecological engineering. Ecological Engineering, 18, 201-210.

COHEN-SHACHAM E., ANDRADE A. et al. 2019. Core principles for successfully implementing and upscaling Nature-based Solutions. Environmental Science & Policy, 98, 20-29.

GOSSELIN, F., 2008. Redefining ecological engineering to promote its integration with sustainable development and tighten its links with the whole of ecology. Ecological Engineering, 32, 199-205.

LUPP G., ZINGRAFF-HAMED A., HUANG J.J., OEN A., PAULEIT S. 2021. Living Labs—A Concept for Co-Designing Nature-Based Solutions. Sustainability 13, 188.

MITSCH, W.J., JORGENSEN, S.E., 2003. Ecological engineering: A field whose time has come. Ecological Engineering, 20, 363-377.

MOREAU, C., COTTET, M. et al. 2022. Nature-based solutions (NbS) : A management paradigm shift in practitioners' perspectives on riverbank soil bioengineering. Journal of Environmental Management, 308, 114638.

NESSHÖVER C., ASSMUTH T. et al. 2017. The science, policy and practice of Nature-Based Solutions: an interdisciplinary perspective. Science of the total environment, 579, 1215-1227.

ODUM H.T., 1963. Man and Ecosystem. Proceedings, Lockwood Conference on the Suburban Forest and Ecology, in: Bulletin Connecticut Agric. Station.

PRETI F., CAPOBIANCO V., SANGALLI P. 2022. Soil and Water Bioengineering (SWB) is and has always been a nature-based solution (NBS): a reasoned comparison of terms and definitions. Ecological Engineering, 181, 106687.

REY F. 2021. Harmonizing erosion control and flood prevention with restoration of biodiversity through ecological engineering used as co-benefits Nature-based solutions. Sustainability, vol.13, 11150.

YOUNG A.F., MARENGO J.A. et al. 2019. The role of nature-based solutions in disaster risk reduction: The decision maker's perspectives on urban resilience in Sao Paulo state. International journal of disaster risk reduction, 39, 101219.

Short term results of different planting technologies applied in the restoration of European habitats

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Keywords: biodiversity, climate change, drylands and desertification, ecosystem services, planting techniques, fog water capture

ABSTRACT

The impacts of climate change are becoming increasingly perceptible and severe. Many semi-arid regions are suffering significant declines in water availability and temperature increases. This has led to faster desertification and more forest fires. It is necessary to implement adaptation measures aimed at reducing the vulnerability of these ecosystems and strengthening their resilience. LIFE Nieblas (LIFE19 CCM/ES/001199) aims to evaluate the mitigation of the different impacts and effects of climate change by testing innovative methodologies of water harvesting and reforestation in Canary Islands (Valleseco, Gran Canaria) and Portugal (Vouzela and Carregal do Sal):

1) Traditional reforestation: settlement and emergency irrigation through hose (TR).

2) Reforestation by means of Cocoons (CO).

3) Reforestation with the use of individual herbivores protection and fog collectors (IFWC).

4) Reforestation using an innovative autonomous irrigation system (AFDS) – this method will only be applied in Gran Canaria.

These innovative methodologies, some of them based on the collection of fog water for watering the planted seedlings on restoration projects, do not significantly increase the carbon footprint, and in some cases, it could even reduce it compared with the traditional methodologies. Their effectiveness and their costs and benefits, including as far as possible the externalities they produce, will be taken into account. The main goals of the project are to demonstrate the effectiveness, efficiency and capacity of the innovative methodologies and the equipment linked to them in contrast to traditional methodologies, and to create synergies between the results of the Project and reforestation, environmental, agrarian, and energy and water management sectors and policies in the EU.
In general, plantations made in Gran Canaria during the 2021-22 campaign presented good results in terms of physiological state (Figure 1). Most seedlings were in good condition (65%), i.e. with all leaves living and with active apexes. However, 24% of the seedlings died after the 2022 summer. Despite those general results, when we analyse the results per treatments, a clear positive influence of innovative treatments was found in comparison to traditional ones (Figure 2). All the innovative planting methods presented significantly higher survival ratios than traditional, where a mortality ratio of 57% was found. In innovative planting methods, mortality ratios were below 20%, and living seedlings were generally in good physiological state. Comparing treatments, IFWC showed the greatest success (89% survival ratio),

followed by AFDS (83%), although in this last treatment a higher percentage of seedlings had more than 25% of leaves dry (affected). In contrast, seedlings in CCN treatment presented a high proportion (23%) of affected seedlings. However, all those results should be taken with care due to the heterogeneity of the IFWC area, where some of the seedlings are rooting in areas with deep soil that could promote an improved physiological state.
Regarding Portugal plantations, seedlings were severely affected during summer 2022 in Carregal do Sal plantations, with a high mortality ratio in TR and IND treatments, because no additional waterings were applied after settlement watering. However, seedlings planted with Cocoon present a high survival ratio for the two species planted (*Quercus robur, Quercus pyrenaica*) which is in concordance with the previous results obtained using the Cocoon technology in the restoration of arid and semi-arid climates (Carabassa et al., 2021).
Traditional reforestation methods tested in both pilot sites seem to increase the plantations failure risk. Innovative water harvesting and reforestation methods seem to increase the efficiency of the plantation actions and reduce mortality ratios. However, the choice of the technology should consider local microclimatic and edaphic conditions in order to take the best profit of innovative technologies.

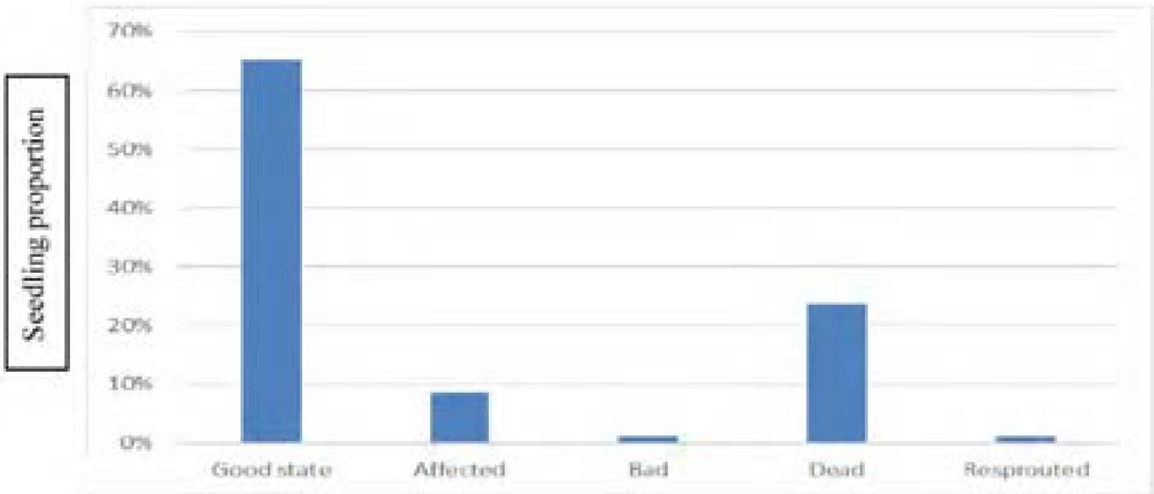

Figure 1. Distribution of the seedlings planted in 2021-22 campaign according to their physiological state in in February 2023. Good state: with more than 75% of green, not wilted leaves. Also, active growing points (apices) may be visible. Affected: seedling with 25-75% of the leaves being wilted, yellow or brown. Bad: severely affected seedling with less than 25% of the leaves being green (i.e., the majority wilted, yellow of brown). Dead: presumably dead seedling with none or only wilted leaves. Resprouted: resprouted seedling.

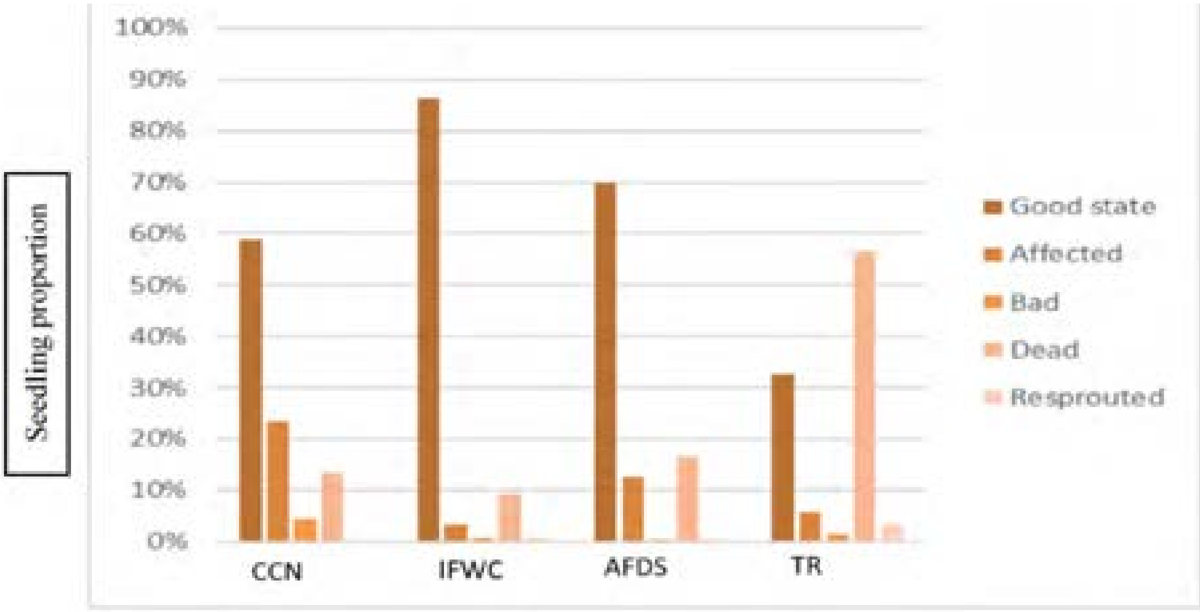

Figure 2. Distribution of the seedlings planted in 2021-22 campaign according to their physiological state in February 2023, per planting method. Cocoon, CCN; individual fog collectors, IFWC; autonomous fluid discharge systems, AFDS; hose irrigation, TR. Good state: with more than 75% of green, not wilted leaves. Also, active growing points (apices) may be visible. Affected: seedling with 25-75% of the leaves being wilted, yellow or brown. Bad: severely affected seedling with less than 25% of the leaves being green (i.e., the majority wilted, yellow of brown). Dead: presumably dead seedling with none or only wilted leaves. Resprouted: resprouted seedling.

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References:

Carabassa, V., Alba-Patiño, D., García, S., Campo, J., Lovenstein, H., Van Leijen, G., Castro, A., González, F., Viera, G., Kourkoumpas, D.S., Zioga, A.A., Papadelis, C.E., Andreu, A., Gimeno-García, E., Kallen, S., Alcañiz, J.M. (2021) Water-saving techniques for restoring desertified lands: some lessons from the field. Land Degradation and Development 33, 133-144. https://doi.org/10.1002/ldr.4134

ECOSYSTEM SERVICES VALUE DYNAMICS UNDER LAND USE ALTERATIONS IN THE UPPER GANGA RIVERINE WETLAND

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Keywords: Riverine wetland, land use and land cover (LULC); ecosystem service value (ESV); value coefficients; coefficient of sensitivity (CS)

ABSTRACT

Riverine wetland ecosystems offer several services like provisioning, supporting, regulatory, and cultural that are crucial to the human well-being and survival (de Groot et al., 2002; MEA, 2005; Costanza et al., 2014).However, urbanization & socio-economic intensification cause alteration in the provision of ecosystem services (ESs) by bringing alterations in land use land cover (LULC). It leads to the conversion of productive croplands, forests and water bodies into barren land and urban areas, diminishing their capacity to provide ESs (Rahman et al., 2011).Despite the extensive research on LULC dynamics in various ecological contexts, the impact of these changes on the loss of quantitative and qualitative ecosystem service values (ESVs) over long-time scales has received limited attention in India (Das & Das, 2019; Pal & Talukdar, 2020; Sannigrahi et al., 2020). This study focuses on the Upper Ganga Riverine Wetland in India to evaluate the changes in LULC and explore the variations in ESs provided by different land use types between 2000 and 2020. Additionally, the coefficient of sensitivity (CS) is assessed to examine the responsiveness of ESVs to LULC alterations.

The study utilizes LULC maps and the value transfer methodology to estimate ESVs. The study area is classified into six land cover types, including water bodies, built-up areas, croplands, forests, sandbars, and unused lands using the Google Earth Engine platform (GIS) (Gorelick et al., 2017).LULC classification took training samples to extract land cover types based on the Random Forest (RF) method. The net value of ESs provided by the different LULC types have been estimated based on the value transfer method employing various unit values e.g. global value coefficients of Costanza et al., 1997 and 2014 (C97, C14) for the years of 2000, 2010 and 2020. To estimate the ESVs using the value transfer approach, the study initially linked LULC types to corresponding biomes, along with their respective ecosystem service value coefficients. This enabled the ESV computation for each LULC type by multiplying the area of each type by its corresponding coefficient. Subsequently, the ESV values for all LULC were then aggregated to determine the total ESV for the landscape in each specific year.

The study reveals a significant increase in the extent of built-up areas, with an average annual change of 30.2% observed between 2000 and 2020. Conversely, water areas and sandbars experienced a marginal decrease of 1.6% and 2.5% annually, respectively, over the same period. The analysis further indicates that during the period from 2000 to 2010, there has been an upward trend in the value of ESs, coinciding with an expansion of water areas by 1.4% per year. However, a decline in ecosystem service values occurred from 2010 to 2020, primarily driven by the decreasing trend in both water areas (-4.0% per year) and cropland. The rate of the net change in total ESV varies from +10.1 to -104.6 (million US$ year^{-1}) based on (Costanza et al. (1997) (C97) and +33.8 to −$52.5 (million US$ year^{-1}) based on (Costanza et al. (2014) (C14) for three phases i.e. 2000–2010, 2010–2020 and 2000–2020. The utilization of the value coefficient (C14) for estimating the loss in ecosystem service value (ESV) yielded a comparatively lower estimate compared to the use of the value coefficient (C97). This difference can be attributed to the higher emphasis placed on cropland and the inclusion of the recreational services value provided by built-up areas in the C14 coefficient. The contribution of individual ecosystem service functions toward the total ESV has also been analysed. The dominance of provisioning services is evident in all the years (approx. 60%), driven by high food production and genetic resources services, as indicated by the value coefficient (C14). Concurrently, there has been a decline observed across all other services, while recreational services have shown an upward trend from 2000 to 2020. Under the C97 coefficient, water supply, disturbance regulation, and

nutrient cycling services have shown a higher level of dominance compared to other services during whole study period.

The coefficient of sensitivity (CS) was calculated to determine the influence of changes in LULC on ESV for the six main land cover types in the study region. This analysis involved adjusting the coefficient values by 50% to assess their impact on ESV changes. It is important to note that the biomes used as proxies may not precisely align with the specific LULC classes. In the riverine wetland, the waterbody demonstrated the highest sensitivity with a range of 0.64 to 0.75. This indicates that changes in the wetland have a substantial impact on ESV, primarily due to its high ecosystem service value coefficient based on the 1997 coefficient. Conversely, when considering the 2014 coefficient, cropland exhibited higher sensitivity with a range of 0.22 to 0.91. This is noteworthy as cropland covers a significant area in the study region and possesses a high ecosystem service value coefficient. The CS values were consistently less than one, indicating that the overall ESV in the riparian zone is relatively insensitive to variations in the coefficients used, indicating robust valuation outcomes. The ESV sensitivity analysis provides valuable insights into the extent to which coefficient values affect ESV changes.

The estimated total ESV loss during the study period (2000-2020) range from -52.5 to -104.6 (million US$ year^{-1}) based on the value coefficients used. The study shows that wetland and forest cover make a substantial contribution to the overall provision of ESs when compared to cropland, as indicated by the 1997 coefficient. However, based on the 2014 coefficient, cropland exhibits a significantly higher contribution. Moreover, the 2014 coefficient assigns importance to built-up areas in terms of ESs i.e. recreational and climate regulation services. Additionally, areas where significant changes have occurred in wetlands, forests, and croplands exhibit a higher rate of net change in ESV, as well as greater sensitivity to fluctuations in ESV. The findings provide valuable insights for ecological, economic, and social gains, facilitating integrated conservation and management strategies for the studied riverine wetland area. The results of this analysis can guide planners and scientists in developing strategies to restore and sustainably preserve ecosystems.

Acknowledgements

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References:

Costanza, R., D'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P., & van den Belt, M. 1997. The value of the world's ecosystem services and natural capital. LK - https://royalroads.on.worldcat.org/oclc/4592801201. *Nature TA - TT -*, *387*(6630), 253–260. https://www-nature-com.ezproxy.royalroads.ca/articles/387253a0.pdf

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S. J., Kubiszewski, I., Farber, S., & Turner, R. K. 2014. Changes in the global value of ecosystem services. *Global Environmental Change*, *26*(1), 152–158. https://doi.org/10.1016/j.gloenvcha.2014.04.002

Das, M., & Das, A. 2019. Dynamics of Urbanization and its impact on Urban Ecosystem Services (UESs): A study of a medium size town of West Bengal, Eastern India. *Journal of Urban Management*, *8*(3), 420–434. https://doi.org/10.1016/j.jum.2019.03.002

de Groot, R., Wilson, M. A., & Boumans, R. M. J. 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics*, *41*(3), 393–408. https://doi.org/10.1016/S0921-8009(02)00089-7

Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., & Moore, R. 2017. Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sensing of Environment*, *202*(2016), 18–27. https://doi.org/10.1016/j.rse.2017.06.031

MEA (Millennium Ecosystem Assessment), 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC.https://doi.org/https://www.millenniumassessment.org/documents/document.356.aspx.pdf

Pal, S., & Talukdar, S. 2020. Assessing the role of hydrological modifications on land use/land cover dynamics in Punarbhaba river basin of Indo-Bangladesh. *Environment, Development and Sustainability*, *22*(1), 363–382. https://doi.org/10.1007/s10668-018-0205-0

Rahman, A., Aggarwal, S. P., Netzband, M., & Fazal, S. 2011. Monitoring Urban Sprawl Using Remote Sensing and GIS Techniques of a Fast Growing Urban Centre, India. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *4*(1), 56–64. https://doi.org/10.1109/JSTARS.2010.2084072

Sannigrahi, S., Chakraborti, S., Banerjee, A., Rahmat, S., Bhatt, S., Jha, S., Singh, L. K., Paul, S. K., & Sen, S. 2020. Ecosystem service valuation of a natural reserve region for sustainable management of natural resources. *Environmental and Sustainability Indicators*, *5*, 100014. https://doi.org/10.1016/j.indic.2019.100014

Session C1: Constructed wetlands technology I

Performance of pilot-scale vertical flow constructed wetlands with and without aeration for municipal wastewater treatment

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Keywords: Constructed wetlands; nature-based solutions; ecological engineering; wastewater treatment; aerated constructed wetlands

ABSTRACT

Constructed wetlands (CWs) are known systems for cost-effective and sustainable wastewater treatment [Sotiropoulou et al., 2023] with robust performance and very low operational cost due to the minimum energy demand, the absence of chemicals, and the minimum operational/maintenance needs [Gomes et al., 2018]. Vertical flow CWs (VFCWs) are nowadays widely used due to their reduced area demand and aerobic nature, providing high treatment efficiency [Stefanakis et al., 2019]. Among the various modifications, the state-of-the-art design development is that of aerated constructed wetlands. In these systems, artificial means are used to maximize the air supply to improve the oxygen availability. Artificial aeration enhances nitrogen removal and has shown a tremendous treatment potential with significantly reduced area requirement [Liu et al., 2016].
In this frame, this study investigated the efficiency of pilot-scale VFCWs on municipal wastewater treatment. In this context, three different aerated VFCWs were implemented, two containing recycled HDPE and one containing gravel as filling mediums, while wetland vegetation was comprised of common reeds (*Phragmites australis*), collected locally in the Chania region. Artificial aeration was applied, in order to investigate its efficiency.

The VFCWs were placed at Technical University of Crete; one containing recycled HDPE with no vegetation (control treatment) (C), one containing recycled HDPE with P. *australis* vegetation (P) and one containing gravel with P. *australis* vegetation (G). During the first year of operation, the units did not receive external aeration, while after that (investigated period), external aeration was applied by adopting a fixed 6 L/h supply rate for one more year of operation. Approximately 12L of primary municipal wastewater, collected from the Municipal Water & Sewerage Company of Chania (DEYAX) were added in each unit every 2 days. Leachate effluent volume was also recorded, to consider the water equilibrium. Influent and effluent samples were taken on a weekly basis to determine the removal of several parameters, such as BOD_5, COD, TOC, Total N, Total P, NH_4-N and PO_4-P. Other parameters, such as pH, Electrical Conductivity (EC) and Total Suspended Solids (TSS) were also monitored.

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References

Gomes, A. C., Silva, L., Albuquerque, A., Simões, R., & Stefanakis, A. I. (2018). Investigation of lab-scale horizontal subsurface flow constructed wetlands treating industrial cork boiling wastewater. *Chemosphere*, *207*, 430-439. https://doi.org/10.1016/j.chemosphere.2018.05.123

Liu, H., Hu, Z., Zhang, J., Ngo, H. H., Guo, W., Liang, S., Fan, J., Lu, S., Wu, H., & Wu, H. (2016). Optimizations on supply and distribution of dissolved oxygen in constructed wetlands: a review. *Bioresource Technology*, *214*, 797-805. https://doi.org/10.1016/j.biortech.2016.05.003

Sotiropoulou, M., Stefanatou, A., Schiza, S., Petousi, I., Stasinakis, A. S., & Fountoulakis, M. S. (2023). Removal of microfiber in vertical flow constructed wetlands treating greywater. *Science of the Total Environment*, *858*, 159723. https://doi.org/10.1016/j.scitotenv.2022.159723

Stefanakis, A. I., Bardiau, M., Trajano, D., Couceiro, F., Williams, J. B., & Taylor, H. (2019). Presence of bacteria and bacteriophages in full-scale trickling filters and an aerated constructed wetland. *Science of the Total Environment*, *659*, 1135-1145. https://doi.org/10.1016/j.scitotenv.2018.12.415

Diffuse pollution treatment wetlands in cold climate: the importance of flood meadows

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Keywords: created wetland design and function, flood meadow, water quality, methane emission, amphibian habitat

ABSTRACT

Wetlands are recognized for their ability to treat diffuse pollution in both urban and agricultural contexts. The designed characteristics of a given constructed wetland impacts the abilities of the wetland to fulfil expectations in water quality treatment performance. Design choices also facilitate the establishment of further ecosystem services by created wetlands. Intermittently inundated flood meadows are an integral part of natural wetland ecosystems, yet they are less commonly associated to constructed wetlands. However, including flood meadows to water treatment wetland designs can improve water quality treatment, increase biodiversity, and control methane emissions.

Two created wetlands located in the boreal region urban centre Nummela, Municipality of Vihti, the Southern Finland Region Uusimaa, were designed and implemented with flood meadows. The two wetlands, named Gateway and Niittu, were studied to assess their impact on water quality improvement. The two wetlands were established in-stream with the wetland Gateway established near the mouth of the stream to the receiving lake Enäjärvi, and the wetland Niittu upstream from Gateway. During mean water level conditions, the inundated area of the Gateway comprises 0,1% of the contributing 550 ha watershed, while the Niittu reaches 0,2%. In Southern Finland stream flood conditions occur during the spring snowmelt season and the fall rainy season with occasional heavy summer thunderstorms adding to these annual flood periods.

In Nummela clay particle transport with associated phosphorus from the watersheds to the receiving lake, suffering from eutrophication, has been a priority driver in constructing wetlands in the area. The 2010 established wetland Gateway was monitored continuously to assess its impact on water quality during the spring snowmelt season over ten years in 2010-2019 and over four full hydrological years in 2012-2016. The monitoring data showed that when relative reduction in clay particle transport (%) is assessed, the wetland purifies water best during the summer dry season when water inflow to the wetland is low. However, when absolute reduction (referring to kg retained) is considered, the wetland purifies water best during the fall rainy season and the spring snowmelt season when water flow conditions are high. Water inflow to Gateway during the monitored periods has ranged from 2 l/s to 1800 l/s. The Gateway wetland inundated area increases during flood conditions owing to the design with a large flood meadow. Assessment of the impact of the densely vegetated with diverse native perennial herbaceous plants flood meadow to water treatment is presented.

The Nummela wetlands were designed with flood meadows including amphibian spawning flood ponds. The Niittu wetland, constructed in 2013-2014, was established with four distinct subsites varying in fish access and with a fishless flood area intended for safe amphibian spawning. Frog (*Rana arvalis* and *R. temporaria*) spawing was monitored over ten years (2014-2023). During the monitoring years the frog

spawning cluster count first steadily increased until habitat bearing capacity was reached for various possible aspects. The flood meadow fishless ponds became most favoured spawning sites by the frogs in which the frog cluster count reached over 500 in five years. The ten-year monitoring period included a warm snowless winter. The spring following this winter was more silent than usual at the frog spawning areas as less than half of the frogs returned to spawn. The development of frog spawning at varying subsites of the Nummela wetlands is presented.

Methane emissions are a concern in water treatment wetlands due to the global warming potential of this greenhouse gas. At the Nummela Gateway wetland methane was monitored for atmospheric fluxes and in water in 2013-2014 when the wetland was still relatively young. At the time the wetland was observed to be a slight source of methane at the annual level, with methane emissions reaching roughly one third of the level of a reference natural fen. Carbon binding in the wetland lush herbaceous vegetation was up to tenfold in comparison to nearby park lawn. Methane was monitored also with the chamber method at various patches throughout the wetland. The emissions observed from the flood meadow patches were significantly lower to the ones observed from the constantly inundated areas of the wetland. The observations of methane emissions across the wetland patches are presented.

Analyses of the Nummela created wetlands' monitoring data on water quality, amphibian spawning, and methane emissions indicate that flood meadows, with associated flood retention ponds, are an important part of wetlands in cold climate regions and need to be considered in diffuse pollution treatment wetland design. Flood meadows are rich in perennial herbaceous vegetation supporting but biodiversity also water treatment during flood periods which in cold climate mainly occur during periods of plant dormancy. Carbon cycling in the flood meadows is directed to plant biomass even more strongly than in the emergent vegetation covered wetland areas thereby reducing methane emissions. Fishless ponds within the flood meadows support amphibians, which yet depend also on the surrounding terrestrial habitat conditions for survival. The Nummela wetlands are located in urban areas where flood meadows with their diverse vegetation also create interest to urban dwellers with the year-round changing colours, forms, and fauna from butterflies to seeds eating birds.

The Nummela wetlands were established with but flood meadows also with a design stressing the importance of shallow emergent vegetation areas within the permanently inundated wetland area. Reference constructed wetlands with wide open water areas lacking vegetation are discussed. Often the lack of vegetation results from establishing wetlands with water levels which are too deep for vegetation establishment. The lack of vegetation reduces a wetland´s ability to perform ecosystem services. A reference wetland is discussed at which the lack of vegetation, and associated limited performance in water treatment, biodiversity and methane emission control, results from soil conditions naturally rich in sulphur. Wetlands design including flood meadows as a mitigation to curtail the challenges associated to sulphur are discussed.

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References:

Kill K., Grinberga, L., Koskiaho J., Mander, Ü., Wahlroos, O., Lauva, D., Pärn J., Kasak, K., Phosphorus removal efficiency by in-stream constructed wetlands treating agricultural runoff: Influence of vegetation and design, Ecological Engineering 180 (2022) 1-11 https://doi.org/10.1016/j.ecoleng.2022.106664

Liu, X., Wahlroos, O., Haapanala, S., Pumpanen, J., Vasander, H. Ojala, A., Vesala,T. and Mammarella, I., Carbon dioxide and methane fluxes from different surface types in a created urban wetland, Biogeosciences, 17 (2020) 3409–3425 https://doi.org/10.5194/bg-17-3409-2020

Valkama, P., Mäkinen, E., Ojala, A., Vahtera, H. Lahti, K., Rantakokko, K., Vasander, H., Nikinmaa, E & Wahlroos, O., Seasonal variation in nutrient removal efficiency of a boreal wetland detected by high-frequency on-line monitoring, Ecological Engineering 98 (2017) 307–317 http://dx.doi.org/10.1016/j.ecoleng.2016.10.071

Wahlroos O., Valkama P., Mäkinen E., Ojala A., Vasander H., Väänänen V.-M., Halonen A., Lindén L., Nummi P., Ahponen H., Lahti K., Vessman T., Rantakokko K. & Nikinmaa E. (2015) Urban wetland parks in Finland: improving water quality and creating endangered habitats, International Journal of Biodiversity Science, Ecosystem Services & Management, 11:1, 46-60, DOI: 10.1080/21513732.2015.1006681

Effects of arbuscular mycorrhizal fungi on the metabolism of ibuprofen in constructed wetland with different substrates

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Keywords: Arbuscular mycorrhizal fungi, Constructed wetland, Ibuprofen, Substrates

ABSTRACT

According to the latest investigation data of Norman Network (NORMAN Association, 2016), more than 1000 EPs which currently not added into the traditional monitoring project by many country have been detected in the environment. Increasing concern has been raised on this issue to reduce potential harm to humans and the environment. (Vazquez-Roig et al., 2011; Balakrishna et al., 2017; Kleywegt et al., 2019). For an instant, ibuprofen is widely used antiepileptics, which can be quantified in aquatic environment at µg/L concentration level in Czech Republic (Vymazal et al., 2017). Arbuscular mycorrhizal fungi (AMF) has been demonstrated the capacity of forming mutualistic symbiosis with roots of over 80% of all land plants, which can obviously improve the metabolic efficiency of host plants by supplying nutrients and promoting host plants growth (Xu et al., 2017). However, it was not clear whether AMF can spontaneously establish in phytoremediation systems constructed to decontaminate wastewater containing EPs. AMF could be a potential biotechnological tool for successful restoration of degraded ecosystems polluted by EPs. However, few studies focus on the role of AMF in removing EPs in CWs. Hence, the objective of this study was to evaluate the effects of AMF on the removal of ibuprofen ant its metabolites in CW systems with different substrates.

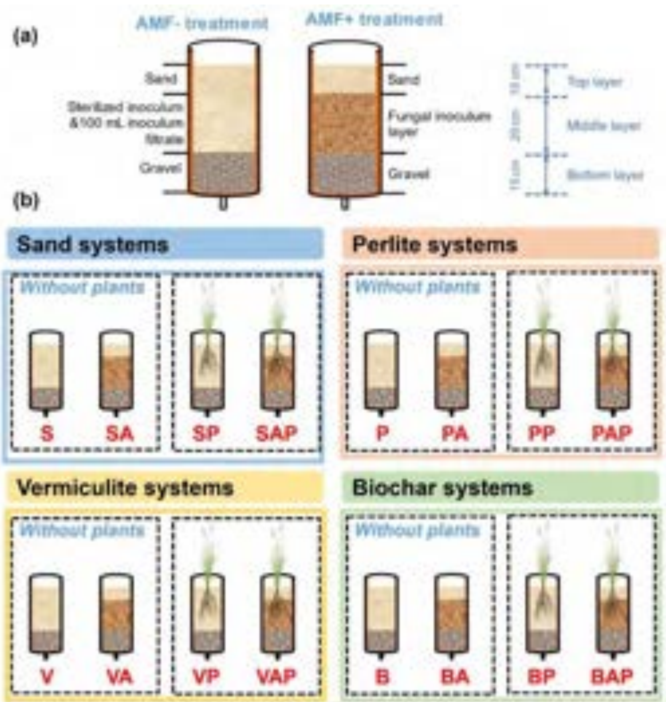

Fig. 1 Schematic diagram of the laboratory-scale vertical-flow CWs. A: 150 mm gravel layer and 350 mm sand layer, AMF non-inoculated (SP) and inoculated (SAP); B, C and D: 150 mm gravel layer, 200 mm absorptive material layer and 150 mm sand layer, B: expended vermiculite, AMF non-inoculated (VP) and inoculated (VAP); C: expended perlite, AMF non-inoculated (PP) and inoculated (PAP)and D: biochar, AMF non-inoculated (BP) and inoculated (BAP), respectively.

In this study, 48 laboratory-scale vertical-flow CWs (plastic column 150 in diameter× 550 mm high) differ in terms of different ratio of substrates, AMF inoculation or non-inoculation, with or without plants (Fig 1). Each CW system was cultivated with *Glyceria maxima* (n=3) and fed with simulated municipal wastewater based on the modified protocol by (Nopens, Capalozza and Vanrolleghem, 2001). In order to promote the formation of AMF symbiosis with plant roots, an intermittent hydraulic loading, which the feeding frequency was 4d/cycle (keep water for 2h and then drain), was designed in this study. CWs operated continuously for five months from July to November. The systems were run with synthetic wastewater for the first three months, afterwards, ibuprofen (500μg/L) was added until the end of the study.
The sample of the inflow and outflow were sampled regularly every 12 days for ibuprofen and its metabolites. Mycorrhizal status was evaluated before the addition of emerging pollutants, including the frequency of mycorrhiza in the root system (F%), intensity of mycorrhizal colonization (M%) and arbuscule abundance (A%) in the whole root system.

Table 1: Mycorrhizal status in plant root under different substrates. Data are presented as means ± SD (n=3).

	F%	M%	A%
SAP	61.34±10.48[a]	11.24±2.47[a]	0.54±0.07[a]
VAP	92.27±3.57[b]	58.17±0.56[b]	1.32±0.02[b]
PAP	83.54±5.63[bc]	26.23±1.34[c]	0.79±0.04[c]
BAP	78.36±6.34[bc]	24.43±1.62[c]	0.67±0.05[c]

a, b and c show the significant difference ($p<0.05$).

The intensity of mycorrhiza in the root system (F%), intensity of mycorrhizal colonization (M%) and arbuscule abundance (A%) were decreased in the following treatments of VAP, PAP, BAP and SAP, respectively (Table 1). AMF colonization, which had the worst performance in sand systems (M%=11.24), were significantly higher in expended vermiculite systems (M%=58.17) than that in other systems ($p<0.05$), while differences were not significant between expended perlite and biochar systems ($p>0.05$).

Biomass of AMF inoculated and non-inoculated *Glyceria maxima*, which grown in different substrates systems, is present in Fig. 2. It is obviously found that substrates have significantly influence of wetland plant growth ($p<0.05$). Comparing with the results of non-inoculated plant, root length, shoot length and plants' weight were increased 6.67~50.72%, 6.10~35.66% and 8.16~13.98%, respectively, indicating that AMF had positive effects on wetland plant growth. In addition, focusing on analysis of AMF inoculated plant with different substrates shows that the biomass results were just the same as previous work (mycorrhizal status shown in Table 1), which was a convincing evidence to prove the positive effects of AMF on plant growth once again.

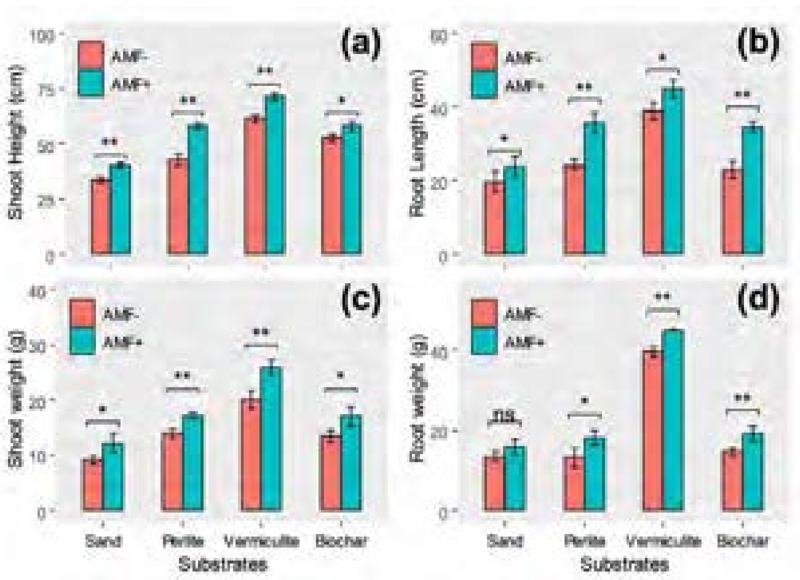

Fig. 2 Height and weight of plant shoots and roots under different treatment, * means p < 0.05, ** means p<0.01.

Two metabolites (ibuprofen-2-hydroxy and ibuprofen-carboxy) were determined in every treatment indicating that they are the main metabolic protection of ibuprofen (Fig. 3). Comparing with non-inoculated systems, the concentration of ibuprofen-2-hydroxy and ibuprofen-carboxy were lower in AMF inoculated systems. In addition, the removal efficiency of ibuprofen in SAP, VAP and PAP systems were increased 14%, 2% and 1%, respectively, indicating that AMF may have positive effects on promoting ibuprofen metabolization.

Moreover, there were significant differences among different substrate systems. It obviously found that removal rate of ibuprofen decreased in the order: biochar > vermiculite ≈ perlite > sand. Biochar showed the optimum removal effect and the average removal rate being nearly 100%. In addition, remarkable differences existed in the concentration of ibuprofen metabolites among different substrate systems, which exposed the capability of substrates to influence ibuprofen removal pathway.

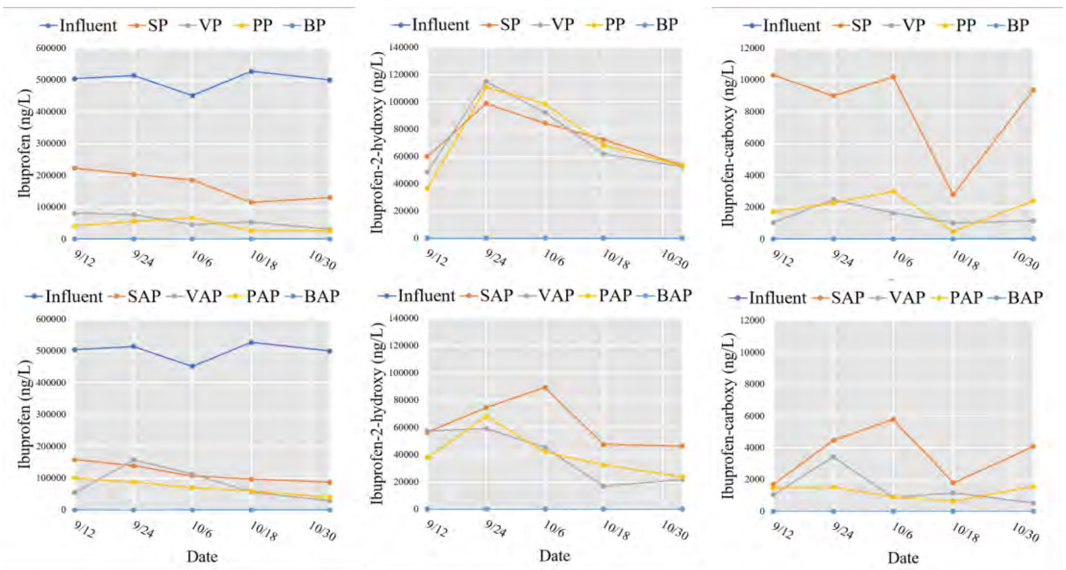

Fig. 3 The translocation of ibuprofen and its metabolites (ibuprofen-2-hydroxy and ibuprofen-carboxy) in the effluent of AMF inoculated and non-inoculated plant CW systems with different substrates.

The results of the study indicated that AMF colonization has positive effects on wetland plant growth and promote the removal efficiency of ibuprofen in CWs. The application of adsorptive substrates, biochar, expended vermiculite and expended perlite, has significant effects on ibuprofen removal.

Acknowledgements

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References:

Balakrishna, K. et al. (2017) 'A review of the occurrence of pharmaceuticals and personal care products in Indian water bodies', Ecotoxicology and Environmental Safety. doi: 10.1016/j.ecoenv.2016.11.014.

Kleywegt, S. et al. (2019) 'Environmental loadings of Active Pharmaceutical Ingredients from manufacturing facilities in Canada', Science of the Total Environment. Elsevier B.V., 646, pp. 257–264. doi: 10.1016/j.scitotenv.2018.07.240.

Nopens, I., Capalozza, C. and Vanrolleghem, P. A. (2001) 'Technical report : Stability analysis of a synthetic municipal wastewater', 32(July).

NORMAN Association (2016) LIST OF EMERGING SUBSTANCES latest update February 2016, Network, Norman. Available at: www.norman-network.net/?q=node/19%0D.

Vazquez-Roig, P. et al. (2011) 'Assessment of the occurrence and distribution of pharmaceuticals in a Mediterranean wetland (L'Albufera, Valencia, Spain) by LC-MS/MS', Analytical and Bioanalytical Chemistry, 400(5), pp. 1287–1301. doi: 10.1007/s00216-011-4826-5.

Vymazal, J. et al. (2017) 'Occurrence and removal of pharmaceuticals in four full-scale constructed wetlands in the Czech Republic – the first year of monitoring', Ecological Engineering, 98, pp. 354–364. doi: 10.1016/j.ecoleng.2016.08.010.

Xu, S. et al. (2017) 'Composition Shifts of Arbuscular Mycorrhizal Fungi between Natural Wetland and Cultivated Paddy Field', Geomicrobiology Journal. Taylor & Francis, 34(10), pp. 834–839. doi: 10.1080/01490451.2017.1280861.

Long term performance of nature-based solutions as decentralized wastewater treatment: a case study of a retail store in southern Italy

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Keywords: nature-based solutions, wastewater, constructed wetland, decentralized wastewater treatment.

ABSTRACT

The aim of this study was to evaluate the removal efficiency and the hydraulic behaviour of a nature-based solution (NBS) used to treat tertiary effluents of the IKEA store in Catania (Eastern Sicily, Italy). The NBS is placed downstream to the conventional wastewater treatment of the store, a sequential batch reactor (SBR), and is made of a horizontal subsurface wetland (HF) and two vertical subsurface flow wetlands (VF1 and VF2) working in series. Chemical, physical and microbiological characteristics of treated wastewater have been evaluated form 2016 to May 2023. The mean removal percentage, for the overall operational life, of TSS, COD and BOD (76%, 73%, 71%), confirm the high reliability of Treatment Wetlands (TWs) for wastewater treatment. *E.coli* concentration was reduced meanly of 4.3 log unit (±1.2). Information on hydraulic properties of the HF unit are extracted from breakthrough curves of a non-reactive tracer (NaCl) and from measurements of hydraulic conductivity at saturation (K_s).

1. Introduction

Nature-based solutions (NBSs), introduced in 2018 by the United Nations World Water Development, are identified as natural processes that can contribute, among other things, to improve the management of water. There is a growing inters to urban applications of NBS, particularly Treatment Wetlands (TWs) for urban wastewater (WW) treatment (Masoud et al, 2022). This paper describes the use of a hybrid TW, combined with conventional system, as NBS for decentralized wastewater treatment.

2. Material and Methods

2.1 System description

The nature-based solution (NBS) at the IKEA® store of Catania (Eastern Sicily,) is made of three TW units and it is the tertiary treatment of wastewater treatment plant. The effluent from the sequential batch reactor (SBR), about 30 m^3day^{-1}, is treated by 3 units functioning in series. The first unit is a horizontal subsurface flow wetland (HF), which has a surface area of about 400 m^2 (12 × 34 m). The effluent of HF is used to feed a VF1, the second stage. The VF1 has a surface area of about 580 m^2 (24 m × 24 m) and the surface is planted with *Cyperus papyrus* var. *siculus* and *Canna indica* at a density of 2 plants m^2. The third and last stage is a vertical subsurface wetland (VF2) with the same design of VF1 (size, area, porous medium), but is planted with *Typha latifolia* and *Iris pseudacorus*. WW effluent from VF2 is used to irrigate green area around the store. The mean Surface Hydraulic Loading Rate (HLR) is 76,6 (mm day^{-1}), the mean Surface Organic Loading Rate (OLR) is 8,8 ($gBOD_5$ m^3day^{-1}) and Cross-Sectional Organic Loading Rate (CS OLR) is 4.4,7 ($gBOD_5$ m^3day^{-1}). Further details about the hybrid TW at the IKEA® store of Catania are given in Marzo et al. (2018).

2.2 Wastewater analysis

At the inlet and outlet of hybrid TW for WW treatment (from 2016), the following physicochemical parameters have been evaluated until May 2023 (about once a month) according to APHA, AWWA, WEF (2017) methods: total suspended solids (TSS), BOD_5, COD, total phosphorus (TP), ammonium ($N\text{-}NH_4$) and total nitrogen (TN). Microbiological parameter, such as *E. coli* is also evaluated according to American

Public Health Association (APHA). The treatment performance of NBS is evaluated as percent removal efficiency for physicochemical parameters, and as $\log_{10}$ reduction of *E. coli.*

2.3 K_s measurements

The falling head method is applied to determine the hydraulic conductivity at saturation (k_s, m d^{-1}) in the HF unit from June 2016 to May 2023. In particular, for each campaign, four falling head infiltration tests are performed around nine piezometers located in the unit (Figure 1). k_s data (4 replicates per measurement point) are recorded along 3 transects (1–2–3; 4–5–6; 7–8–9) that are transverse to the main direction of flow, and along the three transects (1–4–7; 2–5–8; 3–6–9) that are parallel to the main direction of flow. For more details on falling head infiltration tests, see Licciardello et al (2019).

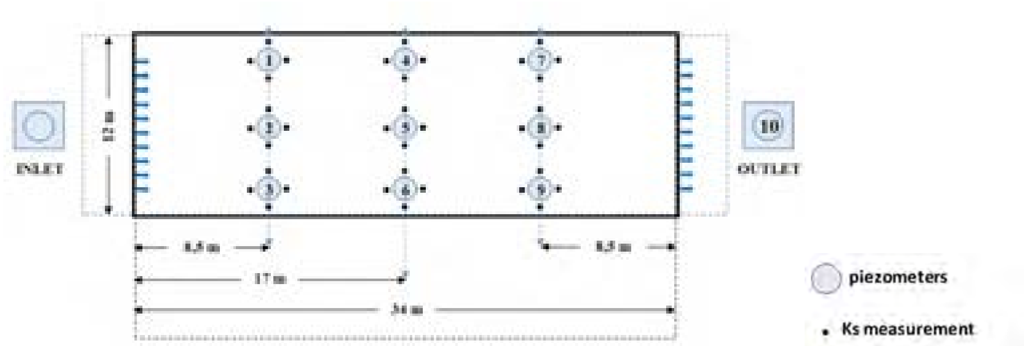

Figure 24. Layout of the HF unit with the localization of the piezometers and the k_s measurement points.

2.2 Tracer test

Tracer test technique is used for evaluating the hydraulic performance of HF substrates. The tracer test gives the Residence Time Distribution (RTD) curve, which indicate the variation in tracer concentrations, measured at the TW outlet, caused by a pulse injection at the TW inlet, as a function of time. In particular, five tests are carried out in HF using NaCl as tracer. From the analysis of the RTD curve of each tracer test, the following main hydraulic indexes are obtained: the actual residence time (t_m), the centroid of RTD curve, and the hydraulic efficiency (λ) calculated as the ration between the time of maximal tracer concentration (t_p) and the nominal residence time (t_n), this latter calculated on a plug flow (PF) assumption as reported in IWA (2000).

3 Result

3.1 Removal efficiency

Table 1 reports the average influent and effluent quality parameters concentrations and the mean removal efficiencies for the NBSs during monitoring period (2006-2023). TSS decreased by 76% from a mean concentration of 70 mg L^{-1} to a mean concentration of 5.5 mg L^{-1} after treatment through the 3 TW units. The average removal efficiency achieved for organic matter is 71% for BOD_5 and 73% for COD, with mean discharge concentrations of 14 and 29 mg L^{-1}, respectively. Nutrient mean removals are 65 % for TN and 32% for TP. The *E. coli* mean removal is 4,3 log units and the average effluent concentrations is 3,3E+01, five order less than the influent. The overall quality of the effluent almost complied the Italian legislation limits (L.D. 152/06 and M.D. 185/03) and EU regulation for WW reuse for irrigation 741/2020.

Table 9. Mean concentration of physical-chemical (mg L^{-1}) and bacteriological (CFU 100 mL^{-1}) parameters at Treatment Wetlands (TW) inlet and outlet during monitoring period (2006-2023). Mean removal in % for chemical parameters and as log reduction of CFUs for E. coli. Standard deviations are reported in brackets.

	n. samples	TW inlet		TW outlet		TW Removal	
		Mean concentration	SD	Mean concentration	SD	Mean concentration	SD
TSS	52	70	(±102.6)	5.5	(±5.5)	76	(±22)
BOD_5	50	92.3	(±94.4)	14.2	(±21.5)	71	(±30)
COD	57	181.1	(±184.9)	29.2	(±38.9)	73	(±28)
TN	46	69.8	(±30.2)	24.2	(±12.6)	65	(±13)
TP	43	14.6	(±7.3)	9.8	(±5.7)	32	(±18)
E. Coli	54	2.2E+06	(±20.8)	3.3E+01	(±8.5E+01)	4.3	(±1.2)

3.2 Hydraulic conductivity

Table 2 reports mean reductions of k_s (in %), respect to the initial value of k_s (clean gravel), measured close to the piezometers located at the same distance from the inlet of the HF (8.5, 17.0 and 34.0 m). k_s values observed since 2016 to 2023 are always lower than the k_s value of clean gravel (equal to 19466 md^{-1}) in all the piezometers. Mean k_s reduction value measured around piezometer 1, 2 and 3 located close to the inlet are the highest in each campaign. The reduction of k_s can be a consequence of clogging of the substrate that occurs mainly at the inlet of the HF unit.

Table 10. k_s mean reduction (in %) respect to the clean gravel along three transects located at the same distance from HF inlet.

Piezometers and distance from the inlet	2016 June	2017 January	2017 April	2017 July	2018 April	2019 February	2020 July	2021 September	2023 May
1-2-3 (8.5 m)	-77	-85	-72	-80	-83	-97	-97	-97	-91
4-5-6 (17.0 m)	-47	-56	-49	-62	-57	-67	-65	-78	-70
7-8-9 (34.0 m)	-66	-64	-47	-63	-68	-69	-69	-63	-66

*k_s=19466 md^{-1}

3.2 Tracer Test

In table 3 are reported tracer response characteristics and hydraulic parameters of HF unit obtained from the analysis of the breakthrough curves in the tracer experiments. The actual residence time (t_m) reduction as well as the hydraulic efficiency decrease with operation time confirm that clogging problems start to affect the HF unit.

Table 11. tracer response characteristics and hydraulic parameters based on tracer experiment carried out in HF

	Tracer mass recovery (%)	Average flow ($m^3 h^{-1}$)	Duration (h)	t_m (h)	t_n (h)	t_p (h)	$\|t_m-t_n\|$ (h)	λ
February 2017	85	1.08	164	64	88	51	24	0.58
May 2017	70	1.02	140	88	92	60	4	0.65
February 2019	94	1.22	195	85	78	62	7	0.79
February 2020	82	1.16	160	83	91	65	8	0.78
May 2023	89	1.19	168	71	80	44	9	0.55

Conclusion

The Natured-based solution (horizontal subsurface flow + vertical subsurface flow + vertical subsurface flow) used as tertiary treatment of wastewater produced by IKEA in Catania, efficiently removed all the monitored parameters. The results of this study confirm the high reliability of Treatment Wetlands for wastewater treatment given that the treatment capacity remained largely unchanged after ten years of operation. The hydraulic parameters obtained from tracer tests and k_s measurements are consistent with each other in highlighting a partial clogging in the inlet area of the HF unit that, in any case, do not affect the overall treatment efficiency of the hybrid TWs.

Acknowledgements

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References:

Aiello R., Bagarello V., Barbagallo S., Iovino M., Marzo A., Toscano A., 2016. Evaluation of clogging in full-scale subsurface flow constructed wetlands. Ecological Engineering 95, 505–513, https://doi.org/10.1016/j.ecoleng.2016.06.113.

APHA/AWWA/WEF, 2017. Standard Methods for the Examination of Water and Wastewater. 23rd Edition, American Public Health Association, American Water Works Association, Water Environment Federation, Denver

Licciardello F., Aiello R., Alagna V., Iovino, M., Ventura, D., Cirelli G.L. 2019 Assessment of clogging in constructed wetlands by saturated hydraulic conductivity measurements. Water Science Technology 79, 314-322, https://doi.org/10.2166/wst.2019.045

Marzo, A.; Ventura, D.; Cirelli, G.L.; Aiello, R.; Vanella, D.; Rapisarda, R.; Barbagallo, S.; Consoli, S., 2018. Hydraulic reliability of a horizontal wetland for wastewater treatment in Sicily. Science of the Total Environment 636, 94–106, https://doi.org/10.1016/j.scitotenv.2018.04.228.

Masoud, A.M.N.; Alfarra, A.; Sorlini, S., 2022. Constructed Wetlands as a Solution for Sustainable Sanitation: A Comprehensive Review on Integrating Climate Change Resilience and Circular Economy. Water 14, 3232. https://doi.org/10.3390/w14203232

Investigating GHG emissions from vertical subsurface flow (VSSF) Constructed Wetlands treating the UASB effluent originating from domestic wastewater

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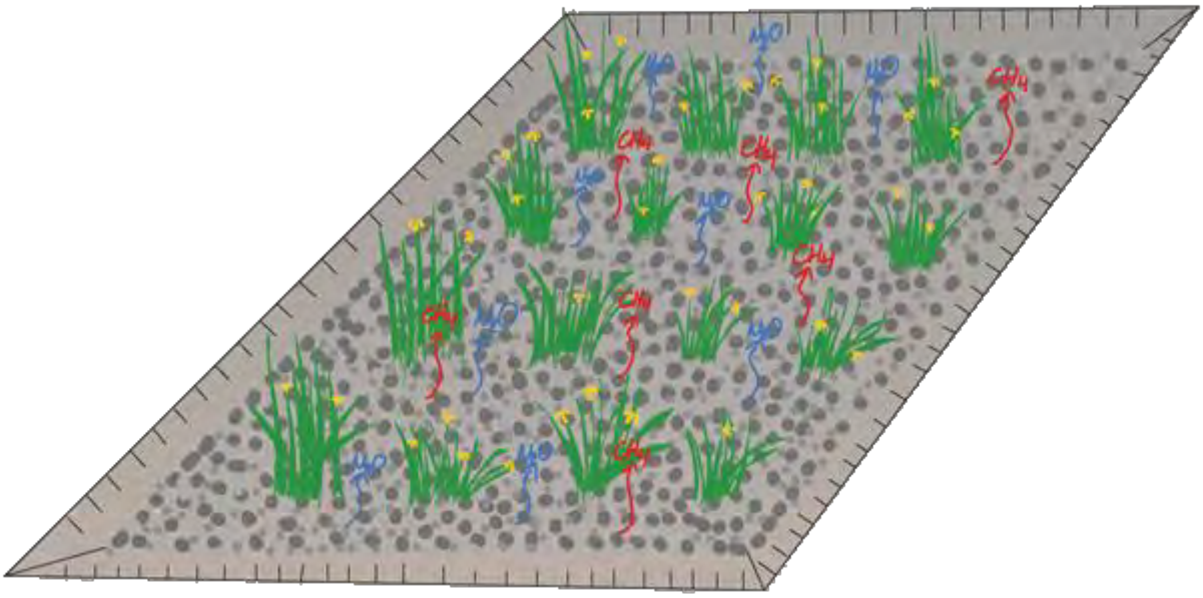
Keywords: Constructed Wetlands, UASB post-treatment, GHG emissions

ABSTRACT



Introduction

This work investigated the greenhouse gas (GHG) emissions from vertical sub-surface flow constructed wetlands (VSSF CWs) receiving the effluent from an upflow anaerobic sludge blanket (UASB) that is treating domestic wastewater. Specifically, methane (CH_4) and nitrous oxide (N_2O) were monitored along with carbon dioxide (CO_2) emissions since they are related to the biochemical regime of a CW. N_2O occurs from a number of different pathways – chemical and biochemical – during both nitrification and denitrification (Colliver & Stephenson, 2000). Little work has been published so far regarding the emissions of GHGs from VSSF CWs.

Materials & Methods

The UASB effluent was treated with a two-stage VSSF CW system. The first stage CW consisted of a saturated bed (VSSF SAT; area of 250 m^2, gravel substrate, planted with *Phragmites australis*; continuous feeding), while the second one was a biodiverse unsaturated bed (VSSF UNSAT; area of 600 m^2, gravel with intermediate sand filter, planted with *Typha latifolia, Juncus inflexus, Iris pseudacorus, Scirpus lacustris*; intermittent feeding). The UASB-CWs system could treat up to 100 m^3/d.

Operation was divided into periods that were mainly characterized by the system flowrate (Q) and temperature (T) since it was the limiting factor for the ambient operation of the anaerobic treatment step (Table 1). The GHG emissions were monitored during three operational periods of the system that were considered as representative according to the limitations of the integrated process throughout a whole year of operation. Those were during winter when system's treatment capacity was low (34.3 m^3/d on

average), during summer when system's capacity approached the design value (82.0 m^3/d on average) and during early summer when a transitional phase was necessary (48.7 m^3/d on average) and was, also, representative for autumn/spring when (i.e., gradual performance decline/increase takes place). The hydraulic loading rate (HLR) ranged from 0.057 to 0.137 m^3/m^2-d for the unsaturated VSSF CW and from 0.137 to 0.328 m^3/m^2-d for the saturated VSSF CW.

Conventional pollutants were analysed according to Standards Methods and GHGs emitted from CWs were determined with an FTIR analyser on-site using the closed hood method on representative points of both the VSSF unsaturated and saturated CW beds. In the case of VSSF unsaturated CW six (6) points were selected for a reference area of 300 m^2, while in the case of VSSF saturated CW five (5) points were selected for the whole CW area (250 m^2) resulting in 1 point / 50 m^2 for both cases. Points were chosen with the following criteria: a) away from the CW slopes to avoid border effects and, b) not covering the plant even though root system was considered fully developed in the whole surface. Surface covering was performed according to Hutchinson & Livingston (1993) and Varga et al. (2015). GHG monitoring focused on the effect of the CW type (saturated vs unsaturated), the possible spatial variation in the same bed under the same conditions (Mander et al., 2008), the effect of loading rate of the CW and, specifically for VSSF unsaturated CW, the possible extra inputs due to the presence of a shallow saturated zone on the drainage layer and the possible temporal effect on emissions throughout the resting period.

Results

During periods 1, 2 and 3, when GHG emissions were monitored, the saturated VSSF saturated achieved 69, 76 and 75% average removal of TSS and 47, 45 and 52% average removal of total COD, while no significant nitrogen transformation was observed (NH_4-N removal ranged from 0 to 10 %). During the same periods the unsaturated VSSF CW achieved 81, 86 and 82% average removal of TSS and 71, 72 and 68% average total COD removal, while nitrification rate was equal to 90, 94 and 96%, respectively, on average while partial denitrification was achieved (11, 16 and 20%, respectively).

Table 12 VSSF CW loading rate during the GHG monitoring

Period	1	2	3
Days	449 - 654	655 - 799	656 – 799
Q_{in} (m^3 d^{-1})	82.0 ± 7.9	34.3 ± 3.7	48.7 ± 2.7
Temperature (°C)	22.7 ± 3.8	15.4 ± 1.9	21.6 ± 1.3
$HRT_{VSSF,SAT}$ (d)	1.5 ± 0.2	3.7 ± 0.4	2.6 ± 0.1
$OLR_{VSSF,SAT}$ (gCOD m^{-2} d^{-1})	81.5 ± 22.2	24.3 ± 8.0	50.5 ± 12.3
$SLR_{VSSF,SAT}$ (gTSS m^{-2} d^{-1})	34.1 ± 12.6	8.3 ± 3.5	19.8 ± 8.1
$OLR_{VSSF,UNSAT}$ (gCOD m^{-2} d^{-1})	17.4 ± 4.0	6.6 ± 1.9	10.0 ± 1.9
$SLR_{VSSF,UNSAT}$ (gTSS m^{-2} d^{-1})	4.6 ± 2.6	2.3 ± 1.1	2.7 ± 2.0
$NLR_{VSSF,UNSAT}$ (gNH_4-N m^{-2} d^{-1})	8.3 ± 1.0	2.7 ± 0.9	5.6 ± 0.4
Resting period$_{VSSF,UNSAT}$ (h)	3.5	8.4	5.9

Results from GHG measurements are expressed in terms of gas flux as mass of carbon or nitrogen in each form per reference area and time (mg m^{-2} h^{-1}) as well as the yield value for the influent carbon and nitrogen load (%). The mass flux results are presented in Table 2 where it can be observed that for the saturated VSSF CW methane flux ranged from 39.8 to 133.0 mgCH_4-C m^{-2} h^{-1} on average and was in general higher than values reported in literature for similar saturated HSSF CW (Mander et al., 2014); this was related both to the anaerobic conditions in the saturated bed and to the presence of dissolved methane in the UASB effluent which was fed to the saturated CW. Methane emissions from the unsaturated CW was generally in accordance with Mander et al. (2014) ranging from 0.6 to 2.3 mgCH_4-C m^{-2} h^{-1}, since dissolved methane was already stripped through the saturated CW. Nitrous oxide emissions from the saturated VSSF

CW were usually in accordance with literature ranging from 0.06 to 1.32 mgN_2O-N m^{-2} h^{-1}, while from the unsaturated CW emissions were always greater than the value range found in literature ranging from 0.24 to 1.13 mgN_2O-N m^{-2} h^{-1}. This could be supported by the fact that the bottom 30cm of the drainage layer was saturated to support partial denitrification besides the typical nitrification in the sand layer. Indeed, low DO concentration, low COD:N ratio and slow growth of denitrifying bacteria are among factors that increase N_2O emissions (Massara et al., 2017).

CH_4 and N_2O emissions were also evaluated in comparison to the influent load; in the saturated CW the yield values ranged from 1.7 to 20.9% and 0.02 to 0.22% for CH_4 and N_2O, respectively, and were in general lower than the usual average values found in literature. The maximum yield methane emissions were observed during the lowest HLR and was related with the higher methane saturation concentration in the UASB effluent.. Regarding the unsaturated CW, yield values for N_2O emissions ranged from 0.19 to 0.43% and were higher than the average value in literature, which was also related with the saturation zone, while the minimum value was observed during the highest load period where the retention time in the saturation zone was minimum limiting the denitrification process. CH_4 emissions ranged from 0.2 to 0.4% and were significantly lower indicating the proper aeration of the bed. Despite the fact that nitrification is not taking place within the saturated CW, N_2O emissions were actually measured, but with lower yields compared to the unsaturated CW. Considering the different HLR and OLR of each system it should be more appropriate to compare yield emissions from the two CW types. In this way, CH_4 emissions was significantly higher and more specifically one order of magnitude greater in the saturated bed, while N_2O emissions were higher in the unsaturated bed, where nitrification was dominant.

Table 13 CH_4, N_2O & CO_2 fluxes from the saturated and unsaturated VSSF CW under variable loading

CW type	HLR (m^3 m^{-2} d^{-1})	CH_4-C (mg m^{-2} h^{-1})	N_2O-N (mg m^{-2} h^{-1})	CO_2-C (mg m^{-2} h^{-1})	CH_4-C/COD_{in} (%)	N_2O-N/N_{in} (%)
unsaturated VSSF	0.137	2.3 ± 0.7	0.44 ± 0.10	162.0 ± 64.2	0.4 ± 0.1 %	0.14 ± 0.03 %
	0.081	0.9 ± 0.5	1.13 ± 0.59	425.1 ± 62.8	0.2 ± 0.1 %	0.43 ± 0.22 %
	0.057	0.6 ± 0.4	0.24 ± 0.10	159.1 ± 60.8	0.2 ± 0.1 %	0.19 ± 0.04 %
Mander et al. (2014)		*2 - 4*	*0.04 - 0.2*	*120 - 210*	*2.3%*	*0.02%*
saturated VSSF	0.328	133.0 ± 51.4	0.48 ± 0.2	253.1 ± 80.5	4.8 ± 1.9 %	0.07 ± 0.03 %
	0.195	39.8 ± 9.3	1.32 ± 0.82	266.8 ± 65.9	1.7 ± 0.4 %	0.22 ± 0.13 %
	0.137	95.7 ± 45	0.06 ± 0.04	79.9 ± 47.5	20.9 ± 9.8 %	0.02 ± 0.01 %
Mander et al. (2014)		*3 - 12*	*0.02 - 0.4*	*120 - 210*	*9.0%*	*0.79%*

Furthermore, the spatial variation for both the saturated and unsaturated CWs and the temporal variation, especially for the intermittently fed unsaturated CW, should be taken into account when GHG emissions are estimated. A series of sampling points were selected for both CW types. Table 2 shows the average values of all the sampling points. Both temporal and special variations of the GHG fluxes were observed. As a representative example, Figure 1 shows the N_2O emissions that were measured in the unsaturated CW when treating 0.057 m^3/m^2-d and the resting period was the longest and equal to 8.4 h. Regarding the temporal variations, in most cases a declining trend was observed throughout the resting period (0 h was directly after the feeding of the bed). Spatial variations in GHG emissions arise due to non-uniform flow patterns in the CW filter media and due to plant growth, decay, expansion etc. as well as due to the accumulation of solids in the feeding pipes. Temporal variations in GHG emissions can be attributed to nitrification/denitrification kinetics and sorption on the material.

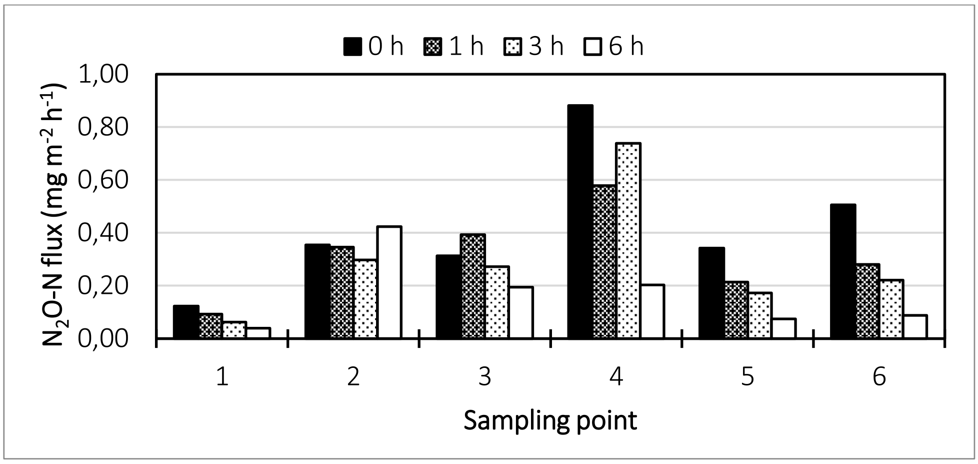


Figure 25 N_2O emissions from the unsaturated VSSF CW during HLR = 0.057 m^3/m^2-d

Conclusions

Key points for the estimation of GHG emissions from wastewater treatment with CWs could be found in the wastewater composition (e.g., anaerobic effluents enhance the emissions of CH_4), the CW type and the physicochemical and biological conditions that prevail in the CW. For example, N_2O yield emissions were greater in the unsaturated CW which aided nitrogen transformation processes compared to the saturated CW. The non-ideal distribution of wastewater in the bed and the effect of the intermittent feeding scheme in typical unsaturated VSSF CWs created spatial and temporal variation.

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References:

Colliver, B. B., & Stephenson, T. (2000). Production of nitrogen oxide and dinitrogen oxide by autotrophic nitrifiers. *Biotechnology Advances*, *18*(3), 219–232. https://doi.org/10.1016/S0734-9750(00)00035-5

Hutchinson, G., & Livingston, G. (1993). *Use of chamber systems to measure trace gas fluxes. Agricultural ecosystem effects on trace gases and global climate change. American Society of Agronomy, Wisconsin, USA 55: 63-78*.

Mander, Ü., Dotro, G., Ebie, Y., Towprayoon, S., Chiemchaisri, C., Furlan, S., Jamsranjav, B., Kasak, K., Truu, J., Tournebize, J., & Mitsch, W. J. (2014). Greenhouse gas emission in constructed wetlands for wastewater treatment : A review. *Ecological Engineering*, *66*, 19–35. https://doi.org/10.1016/j.ecoleng.2013.12.006

Mander, Ü., Lõhmus, K., Teiter, S., Mauring, T., Nurk, K., & Augustin, J. (2008). *Gaseous fluxes in the nitrogen and carbon budgets of subsurface flow constructed wetlands*. *4*. https://doi.org/10.1016/j.scitotenv.2008.03.014

Massara, T. M., Malamis, S., Guisasola, A., Baeza, J. A., Noutsopoulos, C., & Katsou, E. (2017). A review on nitrous oxide (N2O) emissions during biological nutrient removal from municipal wastewater and sludge reject water. *Science of The Total Environment*, *596–597*, 106–123. https://doi.org/https://doi.org/10.1016/j.scitotenv.2017.03.191

Varga, D. De, Ruiz, I., Álvarez, J. A., & Soto, M. (2015). Science of the Total Environment Methane and carbon dioxide emissions from constructed wetlands receiving anaerobically pretreated sewage. *Science of the Total Environment*, *538*, 824–833. https://doi.org/10.1016/j.scitotenv.2015.08.090

Session C2: Bio-based materials I

Plant Growth under Different Bio-composts Applications

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Keywords: Enriched compost, Bio-fertilizers, Organic and inorganic fertilizers, Resource recovery and reuse

ABSTRACT

One of the approaches to support plant growth in coarse unfertile soils is to add different types of organic compost and promote root growth for efficient uptake of water from greater soil volume. Ethylene is a plant hormone that is involved in the regulation of many plant physiological responses especially under stress conditions. Water stress has been extensively associated with elevated release of endogenous ethylene by the plant which results in root growth inhibition dramatically. Therefore, there are certain plant growths promoting rhizobacteria (PGPR) which contain a unique enzyme that decreases ethylene in the inoculated plant roots. The main aim of this study was to evaluate the effect of different bio-composts on plant growth and productivity. For this purpose, different bio-composts made from plant residuals, animal wastes and bio-solids, were applied and tested. They were compared with two bio-stimulants (Stimpo and Regoplant) and grown in three different composts. The study was done in greenhouse using Radish and Okra plants grown in pots and irrigated with freshwater and saline (4 dS/m) treated waste water waters.

Plant showed the best growth under freshwater irrigation compared to saline water. This happened due to salinity stress that affected water and nutrients movements from the soil to the plants. All used composts were positively affected plant growth. However, compost made from bio-solids gave the best growth and productivity even under saline irrigation. The most important thing was how bacteria and bio-stimulants could improve plant growth and give significant effect especially under saline conditions. It was observed that Regoplant was good and gave better results for plant growth (plant height, fresh weight and fruit weight) with freshwater irrigation compared to saline condition. Whereas, Stimpo and bacteria showed positive effect under saline condition and they supported plant growth much better than Regoplant. Using bio-compost enriched with bacteria could be the best option for improving plant growth under saline and dry conditions. It could be a good indicator for saving the environment from chemical fertilizers and improving plants productivity. However, more studies are needed to confirm this findings and shifting to more friendly fertilizers such as bio-fertilizer.

Biomass waste-based material: Electrochemical performances and CO_2 uptake capability.

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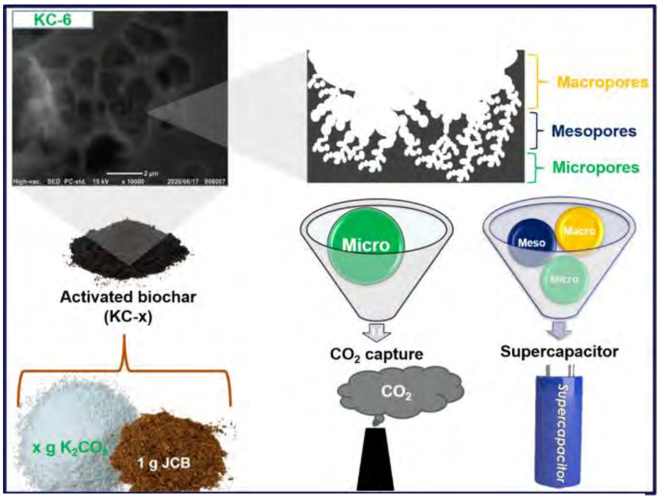
Keywords: Biomass waste; Supercapacitors; CO_2 capture; Bark; K_2CO_3 activation; Biochar.

ABSTRACT

A biomass waste - Japanese cedar bark (JCB) was activated by an environmentally friendly activator - K_2CO_3 to produce porous biochar materials for multiple purposes such as supercapacitors and CO_2 absorbents. The K_2CO_3 activation created a unique hierarchical pore structure with the combination of micro-meso-macropores on the samples' surfaces. The effects of the pore architectures on the electrochemical performance and CO_2 adsorption capability of the activated samples were assessed by using data from the chemical composition, microstructure, gas adsorption isotherms, and electrochemical analytical techniques. The micropores were evaluated to play the most significant part in enhancing the samples' electrochemical capabilities and CO_2 adsorption capacity. Other pore types like mesopores and macropores with the right concentrations also contribute to better electrochemical performance because larger pores make ion diffusion and ion adsorption into micropores more efficient. Meanwhile, mesopores, with the increased content (x) rapidly reduce the CO_2 adsorbed amount (y) according to the linear correlation $y = -0.1104x + 4.3802$. The K_2CO_3-activated biochar with an activation ratio of 6 (6 g K_2CO_3 / 1 g of JCB), named KC-6, was the optimum with respect to both the electrochemical capabilities and CO_2 adsorbed ability. KC-6 had a specific capacitance of 210 F g^{-1} at 10 mA g^{-1}, and *ca.* 4 mmol g^{-1} of CO_2 uptake. This study provided an overview of how pore structures influence the electrochemical behaviours and CO_2 adsorption capability of K_2CO_3-activated carbons derived from JCB, opening a new perspective on multifunctional materials for interdisciplinary applications.



Graphical abstract

INTRODUCTION

Environmental issues for example climate change, global warming, air pollution, and others are receiving increasing attention worldwide. All sectors of society should contribute their parts to mitigate these causes of the ecological problems. The development of CO_2 adsorption methods has long been a subject of research in the field of the environment. There has been a lot of work done in the power industry to increase the effectiveness of energy storage devices, such as batteries, capacitors, and supercapacitors, comprised of eco-friendly materials. In the field of materials, utilizing agricultural and industrial biomass wastes to produce porous biochar materials are being researched for usage in practical applications. Cedar bark is a biomass waste that is reported to have high lignin and cellulose content (Umemura et al., 2014), evaluated as a potential candidate for porous carbon precursors and is also receiving much attention. In this study, it is proposed to fabricate porous biochar materials from Japanese Cedar bark - a type of biomass waste activated by K_2CO_3 - an environmentally friendly activator K_2CO_3 to test CO_2 adsorption capability and electrochemical performances as supercapacitor electrodes.

EXPERIMENTAL

JCB, collected from Imari Wood Market Co., Ltd., was washed with distilled water, dried at 105 °C for 48 h, then crushed into powder. 1 g pretreated JCB powder was well mixed in the water solution with x g of K_2CO_3 (*x* from 0 to 6) for 8 h, before being dried at 105 °C for 2 days. In a tubular electric furnace, the dried sample was activated at 800 °C in N_2 atmosphere at a flow rate of 0.5 L min^{-1}. After activations, the activated samples were washed three times with hot distilled water to remove the excessive activators, then the washed samples were dried at 105 °C for 24 h. The dried activated biochar underwent further analyses. The activated samples were named "KC-x" where "KC" stands for K_2CO_3 and x" is the activation ratio for *x* g of K_2CO_3 per 1 g of JCB. For example, a sample activated by 6 g of K_2CO_3 was labelled as KC-6. Thermogravimetry (TG), and derivative thermogravimetry (DTG), were used to study the thermal behaviour of JCB powder. The microstructures of activated biochar were investigated by using X-ray diffraction (XRD), a Raman spectroscopy, and scanning electron microscop (SEM). The surface elements of KC-x were determined by using X-ray Photoelectron Spectroscopy (XPS). The N_2 adsorption isotherms at 77 K were measured and analysed by a BELSORP analysis program to evaluate the gas adsorption behaviours of all the activated samples. The BET (Brunauer, Emmett, and Teller) method, micropore (MP) plots, α_s plots, and the Barrett-Joyner-Halenda (BJH) plots were performed to understand the porosity properties of KC-x materials. The CO_2 adsorption isotherms at 298 K were measured to estimate the CO_2 adsorbed ability of activated biochar. To evaluate the electrochemical performance of the activated materials, cyclic voltammetry (CV), and the galvanostatic charge-discharge (GCD) processes were performed in 3 electrode cells by using Pt plate, Ag/AgCl, and 1 M H_2SO_4 water solution as a counter electrode, a reference electrode and an electrolyte, respectively.

RESULTS AND DISCUSSION

Material properties

JCB's TG curve had 2 dominant stages of weight loss at 75 °C and 350 °C, which corresponded to the evaporation of water and organic decomposition, respectively. From 700 °C, more than 70 % of the sample mass had decreased and remained relatively stable afterward, so the activation temperature was decided at 800 °C. The K_2CO_3 activation yield was found to be independent of the amount of added activator at around 30 % which was consistent with the thermal examination of the fresh JCB sample. KC-x have two major XPS peaks, C 1s at *ca*. 285 eV and O 1s at *ca.* 288 eV, indicating that they all had carbonaceous structure and some oxygen-based functional groups such as carbonyl (C=O), carboxyl (-COOH), and hydroxyl (-OH) groups. The functional groups can increase the wettability of the electrodes in aqueous electrolytes (Chen et al., 2020). All of the samples had two distinct Raman peaks at 1350 cm^{-1} and 1580 cm^{-1}, which corresponded to the D-band and G-band for disordered porous carbon (Yadav et al., 2020). The value of I_D/I_G increased as the carbonization temperature and activator concentration increased, indicating an increase in the degree of carbon disorder. KC-x displayed two broad, distinctive XRD peaks for the graphitic plane at roughly 23° and 44°, indicating the presence of amorphous carbon with the typical turbostratic structure (Thangavel et al., 2017). The intensities of the peaks at 23°, particularly the (0 0 2) planes, rapidly decreased as the activator was added, showing the presence of structural flaws caused by the randomly aligned aromatic carbon sheets in JCB (Su et al., 2018). The changing surface morphology and topography of KC-x were provided by SEM observation, showing that the macropore density was increased with the increase of K_2CO_3 addition. This behaviour has already been documented in the case of other barks activated by KOH (without pre-carbonization) (Momodu et al., 2017). This suggested that potassium (K) may react with the organics in JCB to produce volatile substances like CO_2, leading to the formation of macropores in the activated sample. The macropore structures of KC-x, which were from submicron to micron order showed hierarchical structures.

Porosity properties

The N_2 adsorption isotherms at 77 K were utilized to characterize the surface area and porosity of KC-x. All biochar samples exhibited a classic type IV isotherm with a prominent hysteresis loop at high pressures (p/p_0 > 0.5), confirming the presence of both micropores and mesopores (Khuong et al., 2022). Furthermore, the existence of macropores is confirmed by the quick vertical rise near p/p_0 from 0.95 to 1 (Wei et al., 2019). The BET and *t* methods were used to determine the specific surface area (S_{BET}), total pore volumes (V_{total}), micropore volumes (V_{micro}), and mesopore volumes (V_{meso}) of the samples based on their N_2 adsorption isotherms data. The S_{BET} of KC-x was found *ca.* 1500 $m^2\ g^{-1}$. The KC-x plots had relatively equal micropore and mesopore volumes, indicating the activations generated by both micropores and mesopores. This result could validate the micropore distribution range ($d < 1$ nm) in the MP plots and the mesopore size (2.5 nm $< d <$ 4 nm) in the BJH plots. At high activation rates, V_{meso} significantly decreased, which revealed that the mesopores might collapse to form the macropore structures observed in SEM images. The MP plots of the K_2CO_3 activations showed one sharp peak between 0.7 and 1 nm. The changing of the micropore types of the different chemical activations was estimated by α_s plots. The α_s plot was obtained by the comparison of experimental adsorption data with a standard isotherm of adsorption on some nonporous solids to identify the micropore types: C-swing (1 nm $< d <$ 2 nm) and F-swing (0.7 nm $< d <$ 1 nm) (Tsubota et al., 2021). The KC-x had only F-swing pore types which were consistent with the uniform peaks in MP plots. The BJH plots exhibited sharp peaks at 2.5 - 4 nm indicating that the K_2CO_3 activation formed controlled mesopore sizes mostly in the region of 2.5 to 4 nm.

CO_2 uptake capability

The CO_2 adsorption capacity was estimated based on CO_2 adsorption isotherms data at 298 K as shown in Fig.1. It was reported that the pore structures had an effect on the amount of CO_2 adsorbed of the sample (Khuong et al., 2022). As shown in Fig. 1a, the volume of CO_2 adsorbed increased as the proportion of the volume of micropores increased, indicating that micropores played a major role in being responsible for CO_2 adsorption on the sample surface. The maximum volume of CO_2 adsorbed was 3.76 mmol g^{-1} when V_{micro} reached 0.6 $cm^3\ g^{-1}$. This result was close to K_2CO_3 activated bamboo-based biochar (Khuong et al., 2022). Fig. 1b shows that the increase of the proportion of V_{meso} (x) rapidly reducing the amount of CO_2 (y) adsorbed according to the linear function y = -0.1104x + 4.3802, indicating the mesopore volume was ineffective for the CO_2 adsorptions. The relationship provides useful information to produce an optimal porous biochar for CO_2 adsorption applications.

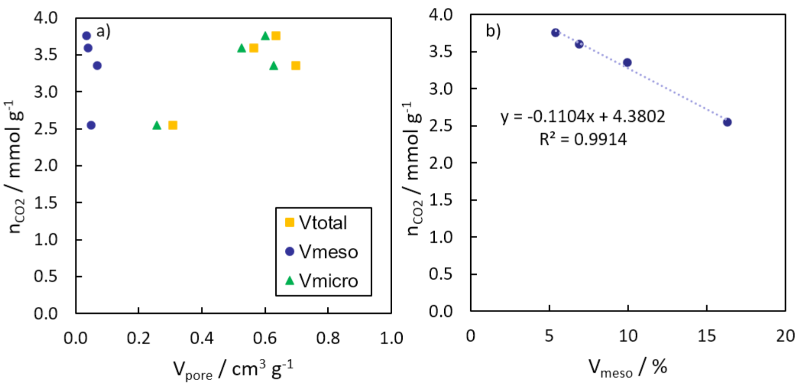


Fig. 1 the relationship of CO_2 uptake amount and a) pore volumes, b) the proportion of micropore volumes.

Electrochemical performances

KC-x (x > 1) had an enhancement of the area of CV curves at 1 mV s^{-1} and GCD curves at 10 mA g^{-1} in comparison to KC-0, because all activators enhanced S_{BET}, pore volumes and functional groups to avail the active sites for electrochemical activity on the surface of the activated samples (Thangavel et al., 2017). Redox peaks on the CV curves became more obvious in samples with high activation ratios, particularly in KC-6. The redox phenomena were confirmed by asymmetric GCD curves, longer discharge lines, and non-linearities that are explained by the self-discharge brought on by faradaic reactions (Lewandowski et al., 2013). The CV and GCD data recognized the charge storage mechanism of these materials based on both electric double-layer capacitors and pseudo-capacitors. Combining the prior XPS, it was determined that the faradaic capacitance was primarily derived from oxygen-containing functional groups such as carbonyl groups (Oh et al., 2014). The equation (1) depicts faradaic redox reactions with carbonyl in 1 M H_2SO_4 water solution electrolyte: $C{=}O + H^+ + e^- \rightleftarrows CHO$ (1)

The area CV curves became largest with the activation ratio of 2 and were gradually decreased beyond this ratio. This observation is attributed to the decrease in the mesopore volume as previously addressed, confirming the relation of the mesopore structure and electrochemical behaviour. The mesopores would shorten the ion transport path and reduce the micropore blockages from the ion accumulation (Chen et al., 2020). The optimum capacitance values were 189 F g^{-1} at 1 mV s^{-1} of KC-2 and 210 F g^{-1} at 10 mA g^{-1} of KC-6, which were higher than reported values in the 1 M H_2SO_4 water solution electrolyte of commercial activated carbon (Onodera and Tsubota, 2022). KC-6 was considered as the optimum sample due to its higher capacitance retention at higher current density, remaining at 71 F g^{-1} at 1000 mA g^{-1}. The well-symmetric GCD lines KC-6 at the high current densities showed the excellent reversibility of the electrolyte ion adsorption and desorption processes in the pores of these electrodes at higher current densities (Chen et al., 2020). It implies that the pore structures of KC-6 were adequate for adsorbing the ions of the 1M H_2SO_4 water solution electrolyte. The Ragone plots with maximum power density (*ca.* 250 W kg^{-1}) and maximum energy density (*ca.* 10.5 Wh kg^{-1}) were acceptable for a supercapacitor, but not optimal in comparison to the different electrochemical cells derived from other barks in different electrolytes (Momodu et al., 2017; Yadav et al., 2020). The optimal experimental setup and better electrolyte selections could provide better results.

CONCLUSIONS

K_2CO_3 -activated biochar derived from JCB had a distinct hierarchical structure combined of micropores (d < 1 nm), mesopores (2.5 nm < d < 4 nm), and macropores (0.5 µm < d < 3 µm). Micropores played an important role in both the adsorption of electrolyte ions and the adsorption of CO_2. While the mesopores and macropores structures had an active role in the diffusion of electrolyte ions into the micropores, these structures, especially mesopores, showed a reduced capacity to adsorb CO_2. KC-6 was optimum sample for both its electrochemical ability as a supercapacitor electrode and its ability to adsorb CO_2. The capacitances at 10 mA g^{-1} and 1 mV s^{-1} of KC-6 were 210 and 189 F g^{-1}, respectively. The CO_2 uptake of KC-6 were *ca*. 4 mmol g^{-1}.

References:

Chen, Z., Wang, X., Xue, B., Li, W., Ding, Z., Yang, X., Qiu, J., Wang, Z., 2020. Rice husk-based hierarchical porous carbon for high performance supercapacitors: The structure-performance relationship. Carbon 161, 432–444. https://doi.org/10.1016/j.carbon.2020.01.088

Khuong, D.A., Trinh, K.T., Nakaoka, Y., Tsubota, T., Tashima, D., Nguyen, H.N., Tanaka, D., 2022. The investigation of activated carbon by K2CO3 activation: Micropores- and macropores-dominated structure. Chemosphere 299, 134365. https://doi.org/10.1016/j.chemosphere.2022.134365

Lewandowski, A., Jakobczyk, P., Galinski, M., Biegun, M., 2013. Self-discharge of electrochemical double layer capacitors. Phys. Chem. Chem. Phys. 15, 8692–8699. https://doi.org/10.1039/C3CP44612C

Momodu, D., Madito, M., Barzegar, F., Bello, A., Khaleed, A., Olaniyan, O., Dangbegnon, J., Manyala, N., 2017. Activated carbon derived from tree bark biomass with promising material properties for supercapacitors. J Solid State Electrochem 21, 859–872. https://doi.org/10.1007/s10008-016-3432-z

Oh, Y.J., Yoo, J.J., Kim, Y.I., Yoon, J.K., Yoon, H.N., Kim, J.-H., Park, S.B., 2014. Oxygen functional groups and electrochemical capacitive behavior of incompletely reduced graphene oxides as a thin-film electrode of supercapacitor. Electrochimica Acta 116, 118–128. https://doi.org/10.1016/j.electacta.2013.11.040

Onodera, H., Tsubota, T., 2022. Dependence of pore structure of activated carbon on the performance of electrical double layer capacitor with NaCl aqueous electrolyte. J Porous Mater. https://doi.org/10.1007/s10934-022-01407-x

Su, X.-L., Li, S.-H., Jiang, S., Peng, Z.-K., Guan, X.-X., Zheng, X.-C., 2018. Superior capacitive behavior of porous activated carbon tubes derived from biomass waste-cotonier strobili fibers. Advanced Powder Technology 29, 2097–2107. https://doi.org/10.1016/j.apt.2018.05.018

Thangavel, R., Kaliyappan, K., Ramasamy, H.V., Sun, X., Lee, Y.-S., 2017. Engineering the Pores of Biomass-Derived Carbon: Insights for Achieving Ultrahigh Stability at High Power in High-Energy Supercapacitors. ChemSusChem 10, 2805–2815. https://doi.org/10.1002/cssc.201700492

Tsubota, T., Tsuchiya, S., Kusumoto, T., Kalderis, D., 2021. Assessment of Biochar Produced by Flame-Curtain Pyrolysis as a Precursor for the Development of an Efficient Electric Double-Layer Capacitor. Energies 14, 7671. https://doi.org/10.3390/en14227671

Umemura, A., Enomoto, R., Kounosu, T., Orihashi, K., Kato, Y., Kojima, Y., 2014. Pyrolysis of Barks from Three Japanese Softwoods. Journal of the Japan Institute of Energy 93, 953–957. https://doi.org/10.3775/jie.93.953

Wei, Q., Chen, Z., Cheng, Y., Wang, X., Yang, X., Wang, Z., 2019. Preparation and electrochemical performance of orange peel based-activated carbons activated by different activators. Colloids and Surfaces A: Physicochemical and Engineering Aspects 574, 221–227. https://doi.org/10.1016/j.colsurfa.2019.04.065

Yadav, N., Ritu, Promila, Hashmi, S.A., 2020. Hierarchical porous carbon derived from eucalyptus-bark as a sustainable electrode for high-performance solid-state supercapacitors. Sustainable Energy Fuels 4, 1730–1746. https://doi.org/10.1039/C9SE00812H

Kitchen waste from cooked food: source of contamination or a valuable source for organic composting serving circular economy perspectives? Use of waste vermicompost as a soil amendment for greenhouse vegetables (II)

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Keywords: vermicompost, kitchen waste, cooked food, circular economy, greenhouse vegetables

ABSTRACT

Reusing, recycling, or recovering waste should be prioritized whenever possible since we live in a world where waste production is constantly rising, and the economic activity associated with it is growing increasingly. Kitchen waste from homes, restaurants, catering services, nursing institutions, and from food processing plants are classified as domestic biodegradable waste. Direct composting of kitchen waste is rather recalcitrant due to its physicochemical characteristics. In line with sustainable development and the circular economy, this study investigated the co-composting of kitchen waste from cooked food of a psychiatric hospital with vermicomposted plant waste and evaluated its utilization as a soil amendment to grow organic crops vegetables. Specifically, the effects of the vermi-co-compost application on the chemical and microbial properties of greenhouse soil of the Green Unit of the Psychiatric Hospital of Thessaloniki were investigated and then related to growth responses and crop production of eruca vecisaria, parsley, and dill, cultivated in the greenhouse. Foliar diagnosis and root analysis was also performed for every crop. The results indicated that growth height and plant mass for all crops increased, while nutrients analysis proved that the vermicompost could effectively be used as a soil amendment, enhancing greenhouse vegetables without added fertilizer.

Introduction

Closing the Loop ((EC), 2015) and *New Circular Economy Action Plan: For a Cleaner and More Competitive Europe* ((EC), 2021), two related action plans that are part of the circular economy strategy, state that Europe should be transformed into a competitive, resource-efficient bioeconomy with a very strong position within the waste economic sector. Among other things, bioeconomy principles rely on the sustainable management of organic wastes and their transformation into products with added value such bio-based products, feed, food, and bioenergy. Reaching the circular economy goals of zero waste creation and zero greenhouse gas emissions from the waste sector requires increased resource recovery from biodegradable waste from the household, industrial, and commercial sectors.

Meanwhile, with economic growth comes a significant increase in the production of kitchen waste, and as a result, threats to the environment are becoming more obvious and limiting the growth of new urban regions (Peng et al., 2022). Kitchen waste from homes, restaurants, catering services, nursing institutions, and from food processing plants are classified as domestic biodegradable waste (Demirbas, 2011). Direct composting of kitchen waste is rather recalcitrant due to its physicochemical characteristics (Peng et al., 2022). Therefore, making organic compost from this waste for use in farming could be a solution to this problem, while using organic compost rather of synthetic fertilizers is more environmentally beneficial

(Bhadwal et al., 2022). Vermicomposting is a green technique that produces vermicompost from different types of organic wastes using specific earthworm species, while it plays a vital role in organic and sustainable agriculture, due to its ability to increase soil fertility and crop nutrition (El Jawaher A. Bin Dohaish, 2020). Moreover, and given that kitchen waste contains a huge quantity of carbohydrates, proteins, lipids, and other organic components, making it a eutrophic environment that support several microbial populations, vermicomposting can reduce and convert organic matter into soluble nutrients and humus in an economical and effective manner, which is mainly attributed to the digestive system of the earthworms (Zhao et al., 2023)

This study investigated the co-composting of kitchen waste from cooked food of a psychiatric hospital with vermicomposted plant waste and evaluated its utilization as a soil amendment to grow organic crops vegetables, cultivated in greenhouses located in the premises of the hospital and with the intention of being used by the hospital kitchens for feeding the patients. This experiment is the second in a series of experiments carried out in the context of the circular economy and sustainable development, with the first involving the vermicomposting of plant waste of the same hospital.

Materials and Methods

Collection of raw materials & Co-compost preparation

Kitchen waste from cooked food and plant kitchen waste of the Psychiatric Hospital of Thessaloniki, Greece, were collected daily, separated, and purified in different recycling bins. Recently purified kitchen waste from cooked food was accumulated in high piles mixed with chopped garden waste, irrigated, and stirred daily and when ready, transferred in the premises of Green Unit of Psychiatric Hospital of Thessaloniki and three rows of dimensions 4m × 2m × 0.5m (length, width, and height) were formed on concrete platforms, vaccinated with vermicompost produced by plant kitchen waste (almost 1 kg m^{-2}). Vermi-co-composting lasted about 45 days.

Application of the vermi-co-compost in organic crops vegetables

The vermi-co-compost was used as soil amendment in organic crop vegetables growth bioassays, to provide an index of maturity and utility of the organic waste. The crops used for the experiment were eruca vesicaria, parsley, and dill grown in the greenhouse of the hospital. The pilot treatments included the use of 100% soil of the premises and soil mixed with vermi-co-compost at a rate of 2.4%. Each treatment included 3 different harvests and each harvest included 3 replications. The progress of the crops' growth (height and biomass) was compared to that of corresponding crops grown in control soil.

Laboratory analysis

Measurements that took place during this project were: chemical and microbial analysis of the partially sun-dried vermicompost, vermi-co-compost and soil, chemical analysis of the treatment' substrate, as well as the record of crops growth measuring the height and the biomass of the crops weekly. Furthermore, nutrients analysis and foliar diagnosis was performed for every crop. All the chemical analysis took place at the laboratory of Soil and Water Resources Institute (SWRI) of the Hellenic Agricultural Organization 'DEMETER' in Sindos, Greece, while microbiological analysis took place at the laboratory of the Veterinary Research Institute of the Hellenic Agricultural Organization 'DEMETER'.

Statistical analysis

Statistical analysis was performed using the SPSS v.27 software. One-way ANOVA was performed to compare foliar analysis results between the treatments. Significant differences between the means of measured parameters were tested at $p < 0.05$ using the Duncan test.

Results and Discussion

Regarding the growth of the cultivated crops, the outcomes indicated that the height and the biomass of the crops was slightly higher in the treatment with the vermi-co-compost addition compared to those cultivated in the control soil, apart from dill height which was slightly lower. The mean values of the three harvests (three replicates per harvest) of the corresponding heights and biomasses of eruca vesicaria, parsley, and dill are shown in Fig. 1.

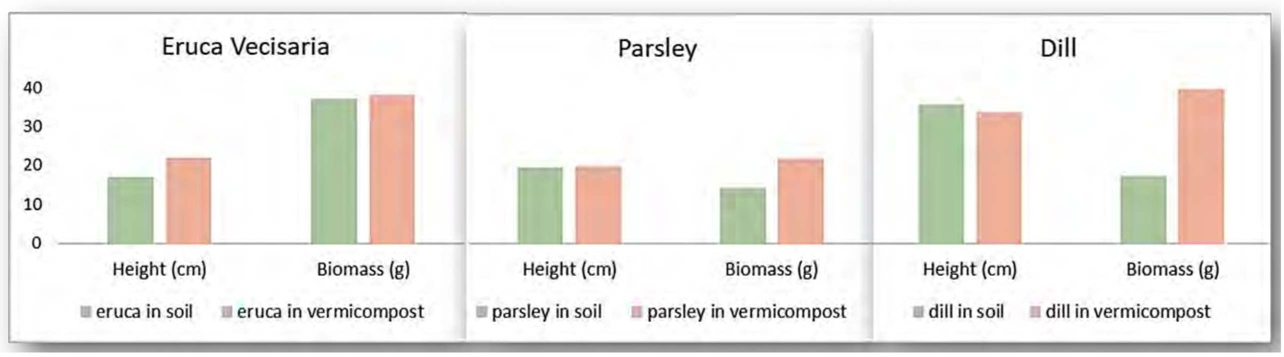

Fig. 1. Mean values of height and biomass of eruca vecisaria, parsley, and dill, grown in control soil and in treatment with vermicompost.

Foliar analysis results of macro- and micro-nutrients of crops grown in control soil and in soil enriched with vermi-co-compost from cooked-food waste are presented in Table 1. It is observed that most nutrient values were slightly to significantly increased in crops grown in soil enriched with vermi-co-compost compared to those grown in control soil, while the parameters that did not increase were within acceptable values according to USDA (U.S. Department of Agriculture (USDA), FoodData Central). Particularly, the increase in nitrogen and potassium is notable in eruca vecisaria and parsley (Fig. 2), while dill exhibited a rise in all micro- and macro-nutrients.

Table 1. Mean values of macro- and micro-nutrients of crops grown in control soil and in soil enriched with vermi-co-compost from cooked-food waste, cultivated in the greenhouse of the hospital.

Parameter*	Eruca Vecisaria		Parsley		Dill	
	Control soil	Vermicompost	Control soil	Vermicompost	Control soil	Vermicompost
N_{kj} (g kg^{-1})	10.3	16.5	16.8	18.1	22.8	23.5
P (%)	0.29	0.36	0.39	0.23	0.25	0.36
K (%)	3.25	4.25	5.15	5.48	4.72	4.75
Ca (%)	3.48	2.27	2.10	1.66	1.76	1.94
Mg (%)	0.70	0.65	0.65	0.52	0.43	0.58
Fe (mg kg^{-1})	162	95.7	79.4	113	50.1	76.7
Mn (mg kg^{-1})	25.5	18.2	75.2	53.0	27.9	40.3
Zn (mg kg^{-1})	36.0	30.8	36.9	30.2	21.8	31.0
Cu (mg kg^{-1})	3.23	3.70	5.68	4.12	2.98	4.13
B (mg kg^{-1})	28.4	26.8	21.3	19.4	16.0	28.9

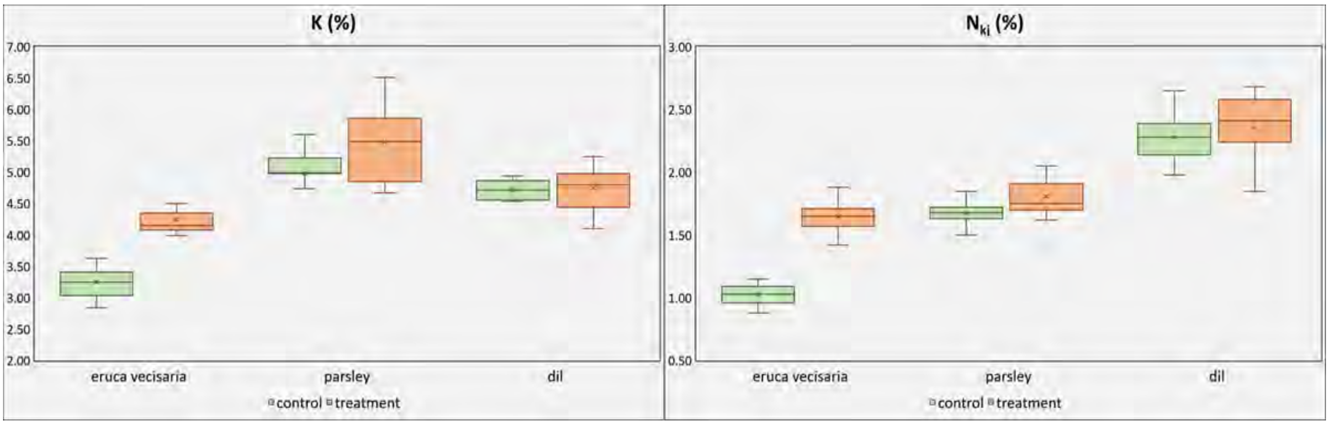

Fig. 2. Boxplots of N_{kj} (%) and K (%) for eruca vecisaria, parsley, and dill, grown in control soil and in treatment with vermicompost.

Concerning heavy metals concentrations, these were lower than ranges considered toxic for soil, groundwater, and human health (Panoras and Ilias, 1999), whilst the results of the microbiological analyses showed that the produced vermi-co-compost is a sanitized product, with the absence of salmonella/25 g and E. Coli content of 103/g, which is below the limit value $2x10^6$ CFU/g DS of the U.S. Environ-mental Protection Agency (EPA) Class B pathogen requirement (Agency, U.S.E.P., 1993).

Conclusions

In line with sustainable development and the circular economy, this study investigated the co-composting of kitchen waste from cooked food of a psychiatric hospital with vermicomposted plant waste and evaluated its utilization as a soil amendment to grow organic crops vegetables, cultivated in greenhouses located in the premises of the hospital and with the intention of being used by the hospital kitchens for feeding the patients. Chemical and microbial analysis of the partially sun-dried vermicompost, vermi-co-compost and soil, and treatment' substrate took place, as well as the record of crops growth measuring the height and the biomass of the crops weekly. Furthermore, nutrients analysis and foliar diagnosis was performed for every crop. Results indicated that the use of the vermi-co-composted product constitutes a beneficial alternative to the use of inorganic fertilizers, but also due to the financial and environmental benefits involved, since it constitutes an environmental-friendly and low-cost practice, recycling and utilizing at the same time kitchen waste from cooked food as well as kitchen plant waste of a psychiatric hospital, solving the problem of their disposal and contributing to the production of organic crops vegetables for feeding the hospital patients.

Acknowledgements

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References:

(EC), E.C., 2015. Communication from the Commission to the European Parliament, the Council, The European Economic and Social Committee and the Committee of the regions Closing the Loop—An EU Action Plan for the Circular Economy. COM (2015) 614/2. Brussels, Belgium, 2015.

Agency, U.S.E.P., 1993. Standards for Use and Disposal of Sewage Sludge. 40 Code of Federal Regulations.

Bhadwal, S., Kumari, N., Kumari, M., Badhan, K., Gomra, S., Manhas, N., Humdani, A.F., Kirmani, F., Shokat, N., Rana, A., 2022. Prepared compost from food waste effectively increased onion production under sub-tropical conditions. Discov. Sustain. 3, 39.

Demirbas, A., 2011. Waste management, waste resource facilities and waste conversion processes. Energy Convers. Manag. 52, 1280–1287. https://doi.org/10.1016/J.ENCONMAN.2010.09.025

El Jawaher A. Bin Dohaish, 2020. Vermicomposting of Organic Waste with Eisenia fetida Increases the Content of

Exchangeable Nutrients in Soil. Pakistan J. Biol. Sci. 23, 501–509. https://doi.org/10.3923/pjbs.2020.501.509

European Commission (EC), n.d. A New Circular Economy Action Plan: For a Cleaner and More Competitive Europe.

Panoras, A., Ilias, A., 1999. Irrigation with treated urban waste, 1st ed. GIAHOUDI-GIAPOULI, Thessaloniki, Greece.

Peng, L., Ma, R., Jiang, S., Luo, W., Li, Yangyang, Wang, G., Xu, Z., Wang, Y., Qi, C., Li, Yanming, Li, G., Yuan, J., 2022. Co-composting of kitchen waste with agriculture and forestry residues and characteristics of compost with different particle size: An industrial scale case study. Waste Manag. 149, 313–322. https://doi.org/10.1016/J.WASMAN.2022.06.029

U.S. Department of Agriculture (USDA) FoodData Central [WWW Document], n.d. URL fdc.nal.usda.gov

Zhao, Q., Zhang, M., Wu, Z., Li, Y., Jiang, J., Qiu, J., 2023. Dynamics of bacterial community in the foregut and hindgut of earthworms with the nutrition supplied by kitchen waste during vermicomposting. Bioresour. Technol. 374, 128777. https://doi.org/10.1016/J.BIORTECH.2023.128777

Material flow analysis of the Organic Fraction of Municipal Solid Waste in EU: monitoring current uses with emphasis on bio-based applications

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Keywords: Material Flow Analysis, Circular Economy, Organic Fraction of Municipal Solid Waste, Valorization, Sankey Diagram

ABSTRACT

The improvement of waste management and the enhancement of circularity constitute focal points in European Union's (EU) Agenda. The Directive 2008/98/EC establishes a waste hierarchy, which prioritizes waste prevention, followed by material recovery and recycling (metal, glass, paper recycling or organic waste composting), energy recovery (through incineration, or digestion of biodegradable wastes) and finally, as least desirable option, disposal (landfilling) with no recovery of materials or energy (Scarlat et al., 2019). In parallel, EU envisions to reach the overall recycling target of 65% for municipal waste by 2035. To achieve this, it is critical to ameliorate the current level of separate collection and the biological management of bio-waste at European level (Gilbert & Siebert, 2022).

According to EU/EUROSTAT guidance on municipal waste data collection, **Municipal Solid Waste (MSW)** comprises household waste and similar waste, bulky waste (e.g. white goods, old furniture, mattresses), yard waste, leaves, grass clippings, street sweepings, the content of litter containers, and market cleansing waste. It originates from households, commerce and trade, small businesses, office buildings and institutions (schools, hospitals, government buildings). It also includes waste from selected municipal services i.e., waste from park and garden maintenance, waste from street cleaning services (European Commission, 2017).

The Organic Fraction of Municipal Solid Waste (OFMSW) is the biodegradable fraction of MSW. **OFMSW** is defined as the mixture of the waste derived from parks, gardens, kitchen, and restaurants. However, its definition is different depending on the region and the nation (Alibardi & Cossu, 2015). The percentage of OFMSW ranges from about 30% w/w for developed countries up to more than 60% w/w for developing countries (Di Maria & Sisani, 2017). In this sense, it is highlighted that the OFMSW is a resource particularly rich in carbon and nutrients and presents substantial potential for valorization routes (Rossi et al., 2022). It is a very attractive resource for Anaerobic Digestion (AD) and an excellent option for the formulation of high-value products in the context of biorefineries. OFMSW can be utilized as feedstock by fermentative microorganisms since it contains considerable amounts of starch and lignocelluloses (Ebrahimian et al., 2023). Indicatively, volatile fatty acids (VFAs) are a valuable compound that may be recovered and can constitute precursors of biopolymers (i.e., polyhydroxyalkanoates (PHAs)) (Rossi et al., 2022).

The valorization of OFMSW into biofuels, bioenergy, and biomaterials is a profoundly beneficial strategy since it substitutes the fossil-based counterparts and the dependency on conventional feedstocks and in parallel alleviates waste management issues and boosts the circularity of European economy. Currently, the improper management of MSW incurs adverse environmental effects, such as contamination of water bodies with organic and inorganic pollutants, the emission of pollutants including dioxins and furans caused by incineration and the emission of a variety of greenhouse gases (GHGs) during the decomposition

of organic waste in landfills (Vergara & Tchobanoglous). In particular, the OFMSW is regarded as a significant contributor to climate change, human health risks, and ecosystem degradation due to high levels of moisture and biodegradability (Demichelis et al., 2022; Alibardi & Cossu, 2015).

In brief, the collected MSW are subjected to pre-treatment processing that includes either mechanical-biological treatment (MBT) or sorting. MSW are subsequently allocated to four broad categories of treatment operations, namely incineration (with and without energy recovery), landfill, composting/digestion and recycling (excluding composting or fermentation) (European Commission, 2017). The implementation of source separation for the digestible/organic fraction of the MSW is a complex decision, contingent on policy targets, local needs and conditions, the feasibility of using available technologies, the quality of collected wastes and applicable socio-economic effects (Al Seadi et al., 2013).

The analysis and evaluation of biological feedstock flows is facilitated by the implementation of Material Flow Analysis (MFA). MFA describes a model for the “systematic assessment of the flows and stocks of materials within a system defined in space and time” (Brunner & Rechberger, 2016). It is a tool that sheds light on the material basis of the economy and the associated economic supply and demand issues. Furthermore, it enables the identification of inefficient use of natural resources, energy and materials in process, value chains or the economy in general, that would go undetected in conventional monitoring systems (Camia et al., 2018; OECD, 2008).

Materials and methods

The principles of MFA have been compiled and adjusted for the investigation of the OFMSW generated in EU-28. The major methodological steps that have been followed are briefly analyzed. Primarily, the goal of the current study is the monitoring and quantification of the OFMSW in EU. The novelty of the study lies in the inclusion of the OFMSW supplied to the bio-based industry, in addition to the conventional management pathways. Therefore, the examined value chain includes: (i) the sources of OFMSW input which encompass domestic generation and imported quantities, (ii) the available amount of OFMSW, and (iii) the flows that exit the system, namely conventional treatment/disposal, composting, anaerobic digestion and bio-based industry, as well as exported quantities. With regard to system boundaries, the analysis is conducted for EU-27 and UK (spatial boundary), on an annual basis (temporal boundary). To avoid time-dependent variations, the mean value of data was calculated for 2019-2021 (most recent data).

Subsequently, every flow and stock of the investigated system is quantified. MFA is intensely data-driven, rendering data mining a step of paramount importance for the robustness and the credibility of the results. A systematic research of databases and official statistical reports has led to the creation of a complete inventory. The necessary data for domestic generation have been sourced from Eurostat. The reported quantities concern MSW and therefore the quantification and allocation of the separate flow of OFMSW requires meticulous processing of the available information.

The OFMSW is assumed to correspond to 34% of the total MSW, as reported in bibliography (European Environmental Agency, 2020; Rossi et al., 2022). Additionally, the traded quantities of OFMSW are retrieved from Eurostat’s data on waste shipments, regulated by the EC Waste Shipment Regulation (No 1013/2006). The European waste codes for which the data was selected are: biodegradable kitchen and canteen waste (20 01 08), edible oil and fat (20 01 25), wood other than that mentioned in 20 01 37* (wood containing hazardous substances) (20 01 38) and biodegradable waste (20 02 01).

The management of the generated MSW, according to the definitions on waste provided by the OECD/Eurostat Joint Questionnaire, includes either the disposal of the materials, via landfilling and incineration, or their recovery. The recovery is achieved through material recycling, composting/digestion and preparation for reuse, while incineration is applied for energy recovery. Detailed data for all these subcategories are provided by Eurostat for MSW, on a country level. However, to elucidate the quantities of OFMSW that correspond to the retrieved data, it is necessary to proceed to certain assumptions. First, it is reasonable to assume that the quantity of MSW destined for composting and AD practically consists of the OFMSW. Also, according to ECN DATA REPORT 2022, 70% of separately collected municipal bio-waste is sent for composting in the EU-27 and 30% of separately collected municipal bio-waste is sent for

AD (Gilbert & Siebert, 2022). Finally, material recycling refers to materials such as paper & cardboard, metals, glass, plastic, textiles and wood and therefore, it is excluded from the OFMSW value chain.

Special emphasis is placed on the retrieval of data for the production of biochemicals and biomaterials from the OFMSW. It is accentuated that the data regarding bio-based industries feedstocks (in terms of quantities) is scarce and there is not any official systematic recording. The indispensable data for the current MFA was collected from IEA Bioenergy Task 42, which is an international platform for collaboration and information exchange concerning biorefinery research and development. In this context, information about the feedstock, production volume, TRL and refining technologies implemented are reported, for a large number of registered biorefineries around the globe. From the screening of the dataset, 15 biorefineries operating with organic waste (including MSW, food waste, oil and fat residues and cooking oil among others) are detected. The majority of them generate biofuels, while the production of poly-3-hydroxybutyrate, nanolignin, bioactives, organic acids, erythritol and fibers is reported as well. To convert the retrieved production volumes of the final products to the supplied feedstock, appropriate conversion factors, tailored to each conversion process, were utilized. Finally, the mass balance is executed so as to quantify any potential unreported imports/uses or losses.

Results and discussion

The information from the databases is collected, assessed and processed as described, so as to extract precise data about the generation and fate of OFMSW in EU-28. The final data is illustrated on Table 1.

Table 14: Balance sheet of OFMSW MFA, EU-28 (data in kt/yr)

Input		Output	
Generation	89,203	Exports	66
Imports	62	Composting	33,267
		Anaerobic digestion	14,257
		Biobased industry	1,681
Total, kt/yr	89,265	**Total, kt/yr**	49,271
Output destined for other uses: 39,944			

The unspecified output quantity constitutes the portion of the OFMSW that is subjected to landfilling or incineration (with or without energy recovery). The results of Table 1 serve as a foundation for the creation of a Sankey diagram so as to present the information in a direct and comprehensive way. Sankey diagrams constitute a visual representation of interlinkages in MFA systems and direct the attention to the essential points. Sankey diagrams exhibit substantial benefits since they have been proven particularly effective for public communications to decision makers in industry, government, stakeholders and the public as well (Schmidt, 2008).

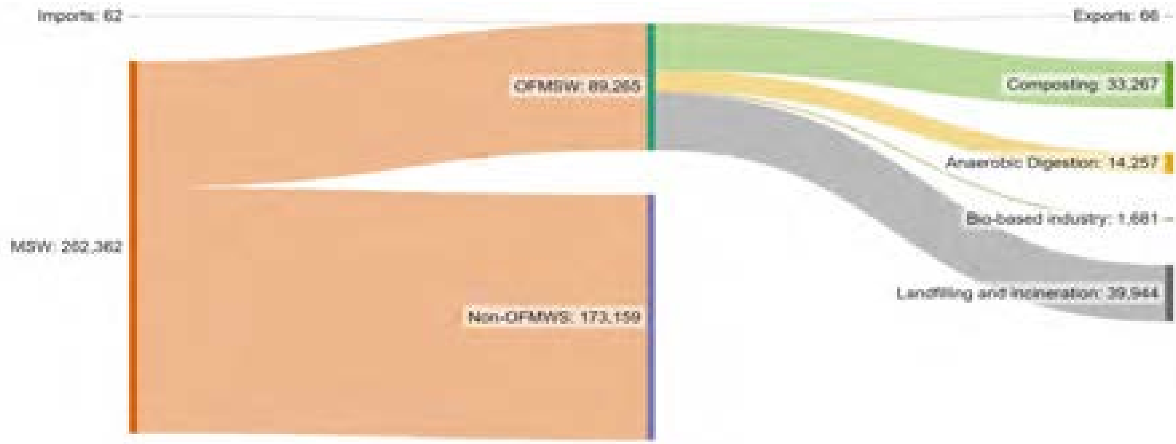

Figure 26: Sankey diagram of OFMSW MFA; Data in kt

Conclusions

The present study provides a representative overview of the management status of the OFMSW in EU-28. Currently, 54% of the generated OFMSW is treated with composting and anaerobic digestion, while almost 44% is landfilled or incinerated. Despite the plethora of beneficial compounds that OFMSW contains, the degree of upcycling is remarkably low, especially in terms of biochemicals and biomaterials. The amount of OFMSW headed for bio-based industry is lower than 2%. However, since a significant amount of OFMSW is collected and treated conventionally, it is deduced that the proliferation of the utilization of OFMSW to higher value applications is a feasible scenario.

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References:

Alibardi, L., Cossu, R., 2015. Composition variability of the organic fraction of municipal solid waste and effects on hydrogen and methane production potentials. Waste Management 36, 147-155, https://doi.org/10.1016/j.wasman.2014.11.019.

Al Seadi, T., Owen, N., Hellström H., Kang., H., 2013. Source separation of MSW. IEA Bioenergy.

Brunner, P.H., Rechberger. H., 2016. Handbook of Material Flow Analysis: For Environmental, Resource, and Waste Engineers, 2nd ed., Second Edition (2nd ed.). CRC Press, https://doi.org/10.1201/9781315313450

Camia, A., Robert, N., Jonsson, K., Pilli, R., Garcia Condado, S., Lopez Lozano, R., Van Der Velde, M., Ronzon, T., Gurria Albusac, P., M`barek, R., Tamosiunas, S., Fiore, G., Dos Santos Fernandes De Araujo, R., Hoepffner, N., Marelli, L., Giuntoli, J., 2018. Biomass production, supply, uses and flows in the European Union: First results from an integrated assessment. Publications Office of the European Union, Luxembourg.

Demichelis, F., Tommasi, T., Deorsola, F.A., Marchisio, D., Mancini, G., Fino, D., 2022. Life cycle assessment and life cycle costing of advanced anaerobic digestion of organic fraction municipal solid waste. Chemosphere 289.

Di Maria, F., Sisani, F., 2017. Greenhouse Gas Emissions and Environmental Impact from Recycling the Organic Fraction of Solid Waste: Comparison of Different Treatment Schemes from a Life Cycle Perspective. Recycling 2, 13, https://doi.org/10.3390/recycling2030013

Ebrahimian, F., Khoshnevisan, B., Mohammadi, A., Karimi, K., Birkved, M., 2023. A biorefinery platform to valorize organic fraction of municipal solid waste to biofuels: An early environmental sustainability guidance based on life cycle assessment. Energy Conversion and Management 283, https://doi.org/10.1016/j.enconman.2023.116905.

European Commission., 2017. Guidance on municipal waste data collection: Eurostat – Unit E2 – Environmental statistics and accounts; sustainable development, D.E.S.a.r. statistics (Ed.).

European Environment Agency., 2020. Bio-waste in Europe — turning challenges into opportunities, Available online: https://www.eea.europa.eu/publications/bio-waste-in-europe

Gilbert, J., Siebert, S., 2022. ECN DATA REPORT 2022: COMPOST AND DIGESTATE FOR CIRCULAR BIOECONOMY - Overview of Bio-Waste Collection, Treatment & Markets Across Europe, EUROPEAN COMPOST NETWORK ECN e.V., Available online: https://www.compostnetwork.info/wordpress/wp-content/uploads/ECN-rapport-2022.pdf

IEA Bioenergy, Task 42: Global Biorefineries Atlas Portal. Available at: https://task42.ieabioenergy.com/databases/

OECD, 2008. Measuring Material Flows and Resource Productivity. Volume I. The OECD Guide, OECD Publishing, Available online: https://www.oecd.org/environment/indicators-modelling-outlooks/MFA-Guide.pdf

Rossi, E., Pasciucco, F., Iannelli, R., Pecorini, I., 2022. Environmental impacts of dry anaerobic biorefineries in a Life Cycle Assessment (LCA) approach. Journal of Cleaner Production 371, https://doi.org/10.1016/j.jclepro.2022.133692.

Scarlat, N., Fahl, F., Dallemand, J.F., 2019. Status and Opportunities for Energy Recovery from Municipal Solid Waste in Europe. Waste Biomass Valor 10, 2425–2444, https://doi.org/10.1007/s12649-018-0297-7

Schmidt, M. (2008). The Sankey Diagram in Energy and Material Flow Management, Journal of Industrial Ecology 12, 173-185, https://doi.org/10.1111/j.1530-9290.2008.00015.x.

Vergara, S., Tchobanoglous, G., 2012. Municipal Solid Waste and the Environment: A Global Perspective. Annual Review of Environment and Resources, 37. 277-309. https://doi.org/10.1146/annurev-environ-050511-122532

Organic-Mineral Composite Material for Removal of Chromium from Natural Water

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Keywords: Chromium, biocomposites, adsorption, chitosan, alginate, expanded perlite

ABSTRACT

In this study, the potential of chitosan and alginate-perlite composites as a possible method for removing heavy metal pollutants was discussed. The objective of this study was to prepare and investigate the sorption behaviour of the bio-composite beads. In addition, the morphology of the expanded perlite and the final composites was characterized by optical observation with a stereomicroscope and a scanning electron microscope (SEM) in terms of particle size distribution and degree of expansion of the perlite expressed by loose bulk density (LBD). Finally, batch experiments were performed to evaluate the adsorption capacity of the prepared beads in natural groundwater contaminated with Cr from the Sarigkiol Basin, Western Macedonia, Greece.

Potentially toxic elements (PTEs) such as Cu(II), Co(II), Ni(II), Cr(IV), and As(III) are frequently detected in both natural groundwater and wastewater from several anthropogenic activities (mining and smelting operations). Elevated concentrations of PTEs are the main cause of water quality degradation which can be caused by both geogenic and human impacts. Chromium in the environment (surface and groundwater, seawater, soils, sediments, rocks, and air) originates from both natural processes such as weathering of ultramafic rocks, and anthropogenic sources such as industrial wastes from metallurgy, refractories, chemicals (e.g., pigments and paints, electroplating, catalysts, tanning, chromium plating), coal combustion and wood preservation (Testa & Jacobs, 2004); Rakhunde et al., 2012). The toxicity of chromium depends strongly on its oxidation state. Trivalent chromium (Cr(III)) is much less harmful than hexavalent chromium (Cr(VI)), which is carcinogenic (Bell et al., 2022, Pietrelli et al., 2020). The permissible level for Cr in drinking water set by the WHO, 2017, and the Greek national authority is 50μg/L (EU recast Drinking Water Directive 2020/2184).

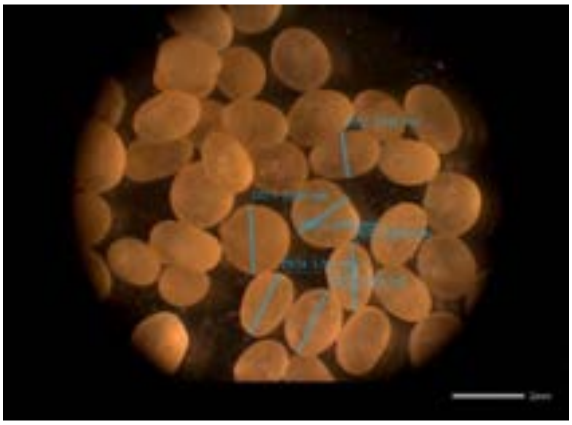
While several techniques exist for removing PTEs from polluted water, they are often too costly or inefficient at low concentrations. The well-known technique of adsorption with activated carbon has led to the exploration of more cost-effective alternatives. Chitosan and alginate are cost-effective adsorbents compared to activated carbon, but their adsorption capacity is low (Hasan et al., 2003).

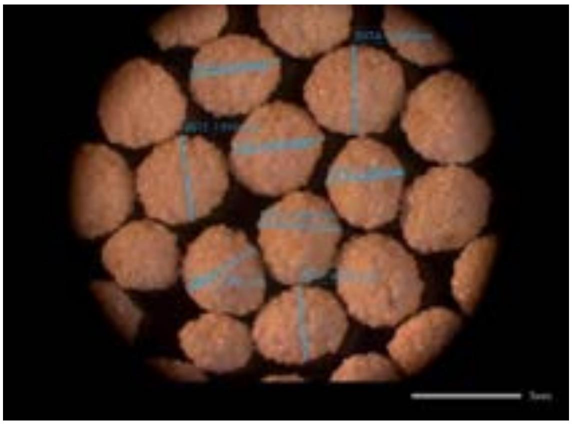
Chitin, an essential component of arthropods and the source of chitosan, is a natural biopolymer. It is a first choice for wastewater treatment because it is environmentally friendly, biodegradable and biocompatible. However, in its natural form or as a gel, chitosan does not readily contain the active binding sites for metal ions, so scientists have been looking for ways to improve this ability. This is accomplished by altering the structure of chitosan and applying it to physical substrates to improve accessibility (Zhou et al., 2005).

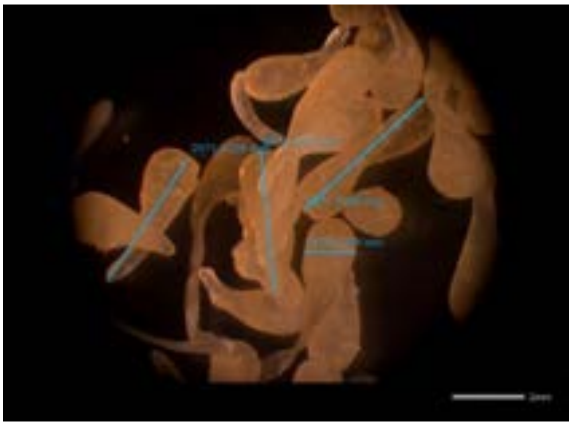
By using alginate and chitosan as raw materials, the synthesized adsorbents can efficiently remove PTEs from aqueous solutions. Alginate is a natural polysaccharide that can be obtained from brown algae. Alginate has some outstanding properties such as high biocompatibility, biodegradability, and is renewable (Gao et al., 2020).

Expanded perlite is a widely used material worldwide. Due to its low bulk density, it is mainly used in building materials technology (as a filler in lightweight composites, for thermal, acoustic and fire insulation), and in horticulture and agriculture (Lanzón & García-Ruiz, 2008).

The removal of three PTEs, i.e., Cu(II), Co(II) and Ni(II), from an aqueous solution using chitosan-perlite composite was investigated in a previous study at in.mat-lab and the National University of Athens. The adsorption of Ni(II), Co(II), and Cu(II) from their ternary solutions onto chitosan-perlite beads was studied and compared with that of pure chitosan in batch studies. The perlite-chitosan composites have shown higher efficiency in removing heavy metals from aqueous solutions. This makes the above bio-composites competitive adsorbents for the removal of Cu (II), Co(II) and Ni(II) from aqueous solutions. The experiments showed that the presence of perlite substrates was beneficial for the adsorption process. The bio-composites with only 50% chitosan exhibited higher efficiency comparable to that of the chitosan reference beads (Simos et al., 2023 under review).
In this study, based on the good results of Simos et al. perlite with different physical properties was used to prepare perlite-chitosan and alginate-chitosan composite beads with different particle size distributions (figure 1) for the adsorption of chromium from natural waters. Graphite atomic absorption spectroscopy (AAS) PE PinAAcle 900T was used to analyse the concentration of Cr before and after water treatment and to evaluate the adsorption capacity of the bio-composite materials. The three biosorption parameters investigated were loose bulk density (LBD), stirring time, and particle size of the perlite substrate. Table 1 shows the prepared expanded perlite substrates used in the batch experiments.


Alginate Reference (a)


Alg-PE-3-50 (b)


Chitosan Reference(c)


C-PE-3-120 (d)

Figure 27: Produced Alginate Ref (a) Alginate-Perlite (b), Chitosan Ref (c), Chitosan-Perlite (d) composites under stereoscopic observation

Table 15: Characteristics of the prepared expanded perlite substrates

Chitosan Reference	
C-PE-3-50	Chitosan and perlite fine grade with particle size=0.3/0.075mm with LBD= 50kg/m^3
C-PE-3-90	Chitosan and perlite fine grade with particle size=0.3/0.075mm with LBD= 90kg/m^3
C-PE-3-120	Chitosan and perlite fine grade with particle size=0.3/0.075mm with LBD= 120kg/m^3
Alginate Reference	
Alg-PE-3-50	Alginate and perlite fine grade with particle size=0.3/0.075mm with LBD= 50kg/m^3
Alg-PE-3-90	Alginate and perlite fine grade with particle size=0.3/0.075mm with LBD= 90kg/m^3
Alg-PE-3-120	Alginate and perlite fine grade with particle size=0.3/0.075mm with LBD= 120kg/m^3

Both materials, alginate and chitosan, are promising (Figure 2) and can potentially be used to remove Cr. The maximum removal capacity of the chitosan-perlite composites observed in the experiments was 72.73%, corresponding to a maximum adsorption capacity of 12.8 μg/g (Figure 2). The maximum removal capacity of the alginate-perlite composites was 52.27%, corresponding to a maximum adsorption capacity of 9.2 μg/g (Figure 3). The use of perlite reduces the amount of organic material by half, resulting in lower cost, while achieving high removal capacity for perlite with LBD of 90 kg/m^3 and 120 kg/m^3. The data obtained in this work show that the morphology of the perlite substrate, the size as well as the open porosity are important parameters affecting the efficiency of the produced bio-composite.

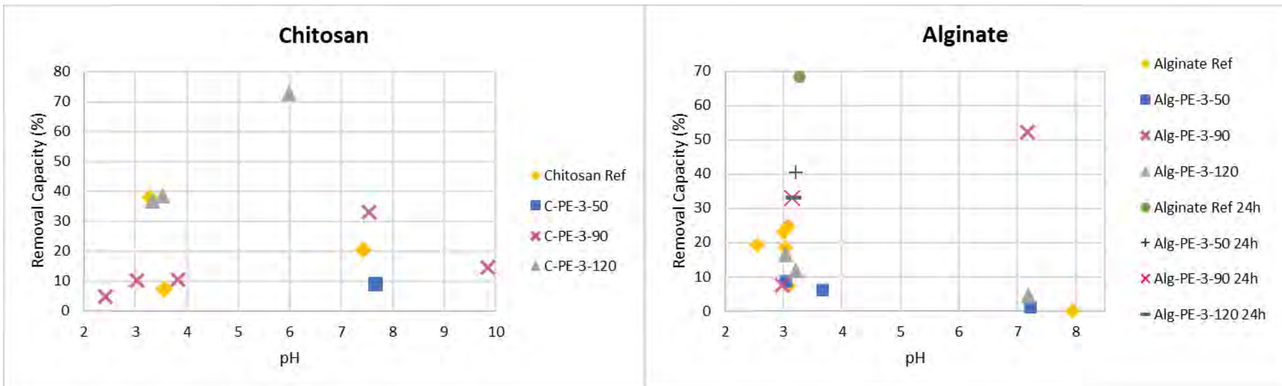


Figure 28: Removal capacity (%) of alginate- and chitosan-perlite composites as a function of pH

The adsorption capacity of chromium in the chitosan-perlite bio-composites studied here (up to 12.8 μg/g at initial concentrations of 72 to 86 μg/l) is quite high; in some experiments much higher than the values reported in the literature.

Furthermore, natural waters contain various concentrations of other ions as well. It is expected that these ions are partially adsorbed as well and possibly affect the capacity of the tested biocomposites regarding Cr.

Overall, perlite can be a good substrate to enhance the sorption capacity of chitosan and alginate, which is an effective technique for adsorption using chitosan-based and alginate-based composites.

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References:

1. Bell, J. et al. (2022) 'Overlooked role of chromium(v) and chromium(iv) in chromium redox reactions of environmental importance', ACS ES&T Water, 2(6), pp. 932–942. doi:10.1021/acsestwater.1c00409.
2. Gao, X. et al. (2020) 'Adsorption of heavy metal ions by sodium alginate-based adsorbent-a review and New Perspectives', International Journal of Biological Macromolecules, 164, pp. 4423–4434. doi:10.1016/j.ijbiomac.2020.09.046.
3. Guidelines for drinking-water quality, 4th edition, incorporating the 1st addendum (2017) World Health Organization. Available at: https://www.who.int/publications-detail-redirect/9789241549950.
4. Hasan, S. (2000) 'Adsorption of ni(so4) on Malaysian rubber-wood ash', Bioresource Technology, 72(2), pp. 153–158. doi:10.1016/s0960-8524(99)00101-7.
5. Hasan, S. et al. (2003) 'Adsorption of chromium(vi) on chitosan-coated perlite', Separation Science and Technology, 38(15), pp. 3775–3793. doi:10.1081/ss-120024229.
6. Hasan, S. et al. (2003) 'Adsorption of chromium(vi) on chitosan-coated perlite', Separation Science and Technology, 38(15), pp. 3775–3793. doi:10.1081/ss-120024229.
7. Lanzón, M. and García-Ruiz, P.A. (2008) 'Lightweight cement mortars: Advantages and inconveniences of expanded perlite and its influence on fresh and hardened state and durability', Construction and Building Materials, 22(8), pp. 1798–1806. doi:10.1016/j.conbuildmat.2007.05.006.
8. Pietrelli, L. et al. (2020) 'Chromium(III) removal from wastewater by chitosan flakes', Applied Sciences, 10(6), p. 1925. doi:10.3390/app10061925.
9. Rakhunde, R., Deshpande, L. and Juneja, H.D. (2012) 'Chemical speciation of chromium in water: A Review', Critical Reviews in Environmental Science and Technology, 42(7), pp. 776–810. doi:10.1080/10643389.2010.534029.
10. Testa, S. and Jacobs, J. (2004) 'Overview of chromium(vi) in the environment', Chromium(VI) Handbook, pp. 1–21. doi:10.1201/9780203487969.ch1.
11. Zhou, D., Zhang, L. and Guo, S. (2005) 'Mechanisms of lead biosorption on cellulose/chitin beads', Water Research, 39(16), pp. 3755–3762. doi:10.1016/j.watres.2005.06.033. 20.

The awarded EUTeens4Green projects to TUC students: promoting nature-based solutions and circular economy

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Keywords*: Circular economy; nature-based solutions; ecological engineering; EUTeens4Green*

ABSTRACT

In 2019, the European Green Deal was signed, aiming to fight climate change and make European society sustainable. The main goal is to reach Carbon Neutrality by reducing drastically the use of fossil fuels, like coal, oil, and natural gas in order to reduce greenhouse gas emissions. Around 200.000 people though are employed in the production of fossil fuels in the EU, and these fuels are often located in specific regions that depend on them economically to survive. To prevent these regions from falling into poverty, Just Transition Fund (JTF) was created to supply €19.5 billion to support the economic conversion of these regions and to contribute to the reskilling of workers employed in fossil fuels production and in regions dependent on carbon-intensive industry.

EUTeens4Green is a program that promotes youth participation into EU Just Transition, achieved by an open call to fund youth-led actions advancing the green transition in EU carbon-intensive regions covered by the Just Transition Fund (JTF). JTF provides financial support up to 10.000€ to young people, aged 15-24, (individuals, groups of youngsters, or youth associations) which are willing to run actions in their community to increase the participation of people affected by the shift to a green economy in one of the EU Just Transition regions. The main objectives of the program are to mobilise youth to take action in the EU Green Transition, empower young people to become active actors in the process, alleviate socio-economic disparities in territories that are most in need and draw recommendations for further involvement of youth in EU Cohesion policy and in the decision-making process of the JTF.

The total budget of the call was 700.000€, where 197 applications from 22 out of the 27 Member States were submitted. 164 of these fulfilled the criteria (aged between 15-24 years old and residency/establishment in a Just Transition territory), out of which 75 youth-led projects from 44 EU carbon-intensive regions were funded. The country with the most funded proposals was Greece, where 13 projects were approved and funded. Three of these funded projects were submitted by the Laboratory of Environmental Engineering and Management of Technical University of Crete (TUC), involving 6 students in total.

Production of biochars for sustainable wastewater treatment and reuse in agriculture
This project aims to the production of biochar from agricultural waste biomass (olive tree waste) to apply it as substrate for Constructed Wetlands (CWs) and as soil amendment to a field receiving treated wastewater irrigation. Biochar is a carbon-rich material with multiple agricultural and environmental applications, being valuable as soil amendment by augmenting the retention of fertilizers and supporting the growth of beneficial soil microorganisms, having on the same time the ability to remediate organic and inorganic contaminants from water and soil. CWs is a low-carbon, nature-based solution for wastewater treatment that adopts the use of natural processes and materials and requires up to 90% less energy compared to conventional methods, something that is significantly important for small regions like Crete and other islands that still largely rely on fossil fuels for energy production. In this context, 4 pilot-scale CWs are going to be constructed using olive tree waste biochar as substrate, to treat municipal wastewater. The treated wastewater is going to be further applied to irrigate a biochar amended test field.

Implementing a green roof to support the just transition

This project aims to the installation of a demo green roof in one building of the School of Chemical and Environmental Engineering, at the TUC campus in Chania. Green roofs are nature-based solutions that counteract several environmental and socio-economic problems associated to urban sprawl and climate change. They also support the cities' transition towards resilience and improved use of our resources and add natural elements to the urban environment, increase the green space, enhance the urban biodiversity and contribute to energy efficiency of buildings. Figure 1 depicts the site where the green roof is planned to be installed and the unplanted terrace that it is going to be compared with. The project will involve the planting of 300 local plants and shrubs, monitoring of the weather conditions, installing a data logging weather station to measure weather parameters (temperature, rainfall, humidity etc) and non-weather parameters such as soil moisture on a continuous basis, temperature and humidity sensors on both roofs to compare the results and the effect on microclimate regulation after the green roof installation and monitoring of the runoff on the two roofs (with/without green roof). Figure 2 depicts the completed green roof at TUC.

Figure 1: Project installation location

Figure 2: Completed green roof at TUC

Promoting circular economy in just transition regions

The idea of this project is to establish a collaboration between two just transition regions of Greece, Chania (Crete) and Florina (Western Macedonia) and jointly promote the concept and the principles of circular economy, by organizing two events, one in each region and by establishing a website hub for circular economy in Greece. In these events, invited academics, professors, professionals, entrepreneurs, authorities working and/or applying circular economy principles will analyze and present circularity case studies from each region and a discussion panel on circular economy is going to take place. Moreover, a website hub with information about the concept and principles of circular economy, database and case studies in the regions are going to be added continuously.

Session C3: Ecosystem services provision and assessment

Assessing and mapping yearly ecosystem services supplies in areas affected by land degradation processes with the support of remote sensing indices: two case studies from the NewLife4Dryland project.

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Keywords: Ecosystem Services; Land degradation; Remote Sensing Indices; Forest fires; Drought.

ABSTRACT

The choice of how to estimate and map ecosystem service indicators depends on several factors, among which the overall purpose of the ecosystem service assessment, the data availability, the type of measurement needed to quantify the indicators, and the availability of human and financial resources. This contribution presents the results of an ecosystem services (ES) assessment and mapping in two Spanish case study areas carried out within the framework of the preparatory LIFE Project NewLife4Drylands (LIFE20 PRE/IT/000007, https://www.newlife4drylands.eu/language/en/). The purpose of the assessment is to integrate ground data and existing thematic data layers with remote sensing observations to account for temporal variations in ecosystem services supply with reference to a baseline. The proposed approach is tailored to tackle situations with limited or no availability of measured ground data and relies on the use of existing GIS data from freely accessible web resources and remote sensing indices (RSI) retrieved via Google Earth Engine (GEE, Gorelick et al., 2017).

The two case study areas (Fig. 1) are located in Gran Canaria, El Nublo II-Tamadaba (ca 265 km^2) and in Catalonia, El Bruc (ca 12.9 km^2). El Nublo II-Tamadaba, in the Gran Canaria Biosphere Reserve is include two Natura 2000 Areas: a Site of Community Importance (SCI) and a Special Area for Conservation (SAC). The area presents an average elevation of 873 m (ranging from 0 to 1872 m). Inside this big area we can find desertification processes triggered by severe herbivorism (wild goats), wildfires (fire event in 2019, ca. 13000 ha affected) and the arid climate (average rainfall around 200 mm/y). El Bruc site, located at an average elevation of 494 m (range 355-585 m) has a Mediterranean climate, with a precipitation average of 666 mm/y, 46 average days of rain, and more than 3 dry months. The area went under a natural fire in 2015 which burnt ca. 1000 ha. It represents a protection and connection corridor for the Montserrat-Roques Blanques-riu Llobregat SCI, an emblematic area with a high touristic, aesthetic and ecological value.

The assessment in the two areas has focused on three ecosystem services: above ground C stock (AGCS), soil erosion control (SEC), and above ground biomass (AGB). The first two are regulating services, while the third is a provision service (Haines-Young and Potschin, 2018). Given the lack of measured ground data the following were taken as proxies for the target services: i) MODIS (MOD17) net primary production (kg C m^{-2}, Running et al., 2004) for above ground C stock; ii) RUSLE based amount of soil mass retained by vegetation computed as the difference between potential and actual soil erosion (Mg ha^{-1} y^{-1}, Panagos et al., 2022) for soil erosion control; and iii) Sentinel2 Normalised Difference Vegetation Index (NDVI, Rouse et al., 1974) for above ground biomass. A different reference baseline year for ES assessment was taken in the two areas, 2016 in Tifaracás and 2019 in El Bruc, so to use RSI from the Copernicus-Sentinel2 repository which are available from 2015. The time series considered for ES assessment and mapping is 2015-2022 in El Bruc and 2016-2022 in Tifaracás.

Given the different spatial resolution of the available raster layers for the three proxies, i.e. 500 m for MOD17, 100 m for soil erosion and 10m for NDVI, there was the need to rescale the first two to the desired resolution of the final maps, which was set to 25 and 10 m for El Nublo II-Tamadaba and El Bruc respectively. The downscaling resorted to stepwise multiple linear regressions (MLR) calibrated over

gridded data points which were used to sample the proxies' raster layers for the selected baseline years along with a number of predictor variables available at the target resolutions of the final ES maps. The predictors were chosen among several RSI indices (time dependent), and terrain, soil, and landscape attributes (time invariant) based on correlations analysis. Using the MLR calibrated for the ES proxies, it is possible to estimate them for all the other years of the time series up to 2022 using the annual median values for all the RSI predictors, and to assess relative difference with reference to the selected baselines. In the case of AGB, though, the comparison with the baseline is straightforward as the indicator is based only on NDVI which is already available at the target resolution.

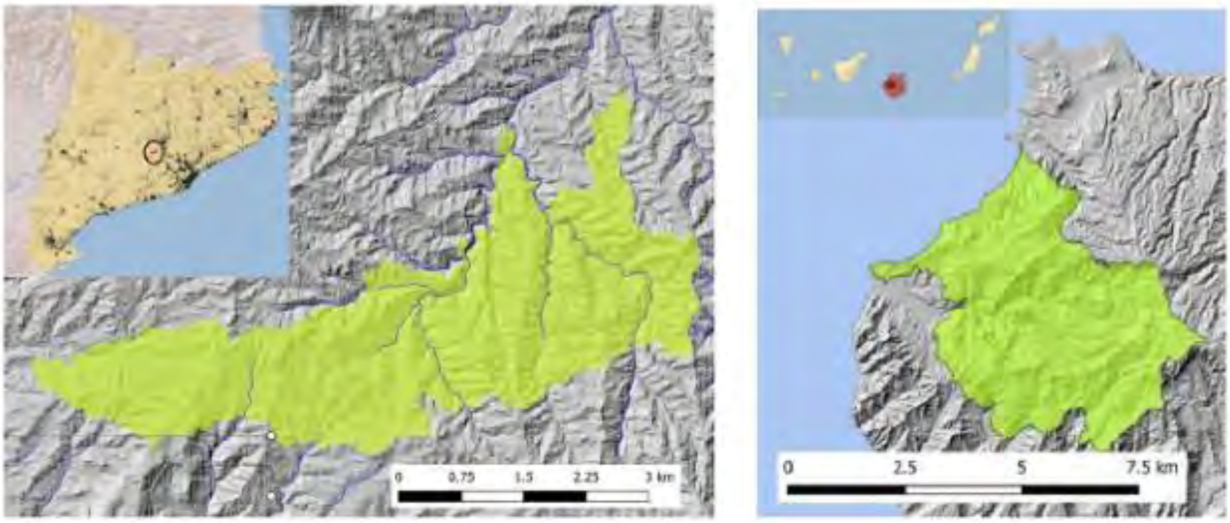

Figure 1. Location of the two case study sites: El Bruc (left) and El Nublo II-Tamadaba (right).

Although in the case of AGCS and SEC the outcomes can be expressed in terms of biophysical units, respectively Mg C ha^{-1} and Mg ha^{-1} y^{-1}, it is preferred to standardize the values resorting to an interval normalization (Wu et al., 2013). Using standardised values, it is possible to compare, and possibly map, different services or the same services across regions or over time. In this way indicator values are normalized resorting to the baseline relative scales, and range from 0 to 1, where 0 represents no relevant ecosystem service supply. Lack of relevance does not mean that a given ecosystem service is not provided but rather that its level of supply is relatively the lowest with respect to the service provided by other spatial units within a given ecosystem. At the other end of the scale, 1 represent the maximum level of ecosystem service supplied by a given ecosystem type.

Table 1. ES Indicator yearly mean values and their relative changes with respect to the baseline (in bold)

	El Bruc						***El Nublo II-Tamadaba***					
	AGB		**AGCS**		**SEC**		**AGB**		**AGCS**		**SEC**	
Year	*Mean*	*Rel. Change*	*Mean*	*Rel. Change*	*Mean*	*Rel. Change*	*Mean*	*Rel. Change*	*Mean*	*Rel. Change*	*Mean*	*Rel. Change*
2015	0.14	-70.5%	0.17	-55.8%	0.29	-18.0%						
2016	0.30	-36.5%	0.25	-37.0%	0.32	-8.0%	**0.54**	**0.0%**	**0.40**	**0.0%**	**0.29**	**0.0%**
2017	0.35	-26.7%	0.29	-25.8%	0.33	-5.6%	0.52	-3.6%	0.38	-6.0%	0.28	-2.5%
2018	0.51	7.5%	0.43	8.9%	0.36	1.8%	0.54	-0.3%	0.40	-0.7%	0.28	-1.4%
2019	**0.48**	**0.0%**	**0.40**	**0.0%**	**0.35**	**0.0%**	0.52	-3.8%	0.38	-6.5%	0.29	-1.0%
2020	0.56	17.8%	0.47	17.6%	0.37	3.8%	0.49	-10.5%	0.34	-15.0%	0.28	-2.3%
2021	0.46	-3.3%	0.37	-6.6%	0.35	-1.1%	0.53	-2.8%	0.39	-2.8%	0.29	-0.7%
2022	0.23	-51.3%	0.34	-13.7%	0.33	-6.0%	0.45	-17.2%	0.33	-18.4%	0.27	-4.9%

Table 1 summarizes the results for the three ES indicators in the two sites in term of ES indicator mean values and its relative changes with respect to the baseline year adopted for the assessment. From the values in the table, it can be observed that in the case of El Bruc the most relevant changes occur in 2015 and 2016, after the forest fire and again in 2022 as result of the prolonged drought that affect most of Europe. In El Nublo II-Tamadaba, the effect of the forest fire has also a notable impact on the loss of ES supply in 2020, but the loss due to the 2022 drought appear to be more pronounced, since it affected the whole area. Figure 2 and 3 depict the maps of the three ES indicators respectively for El Bruc and El Nublo II-Tamadaba for the baseline year, for the year affected by the fire events in the two areas and for the year 2022.

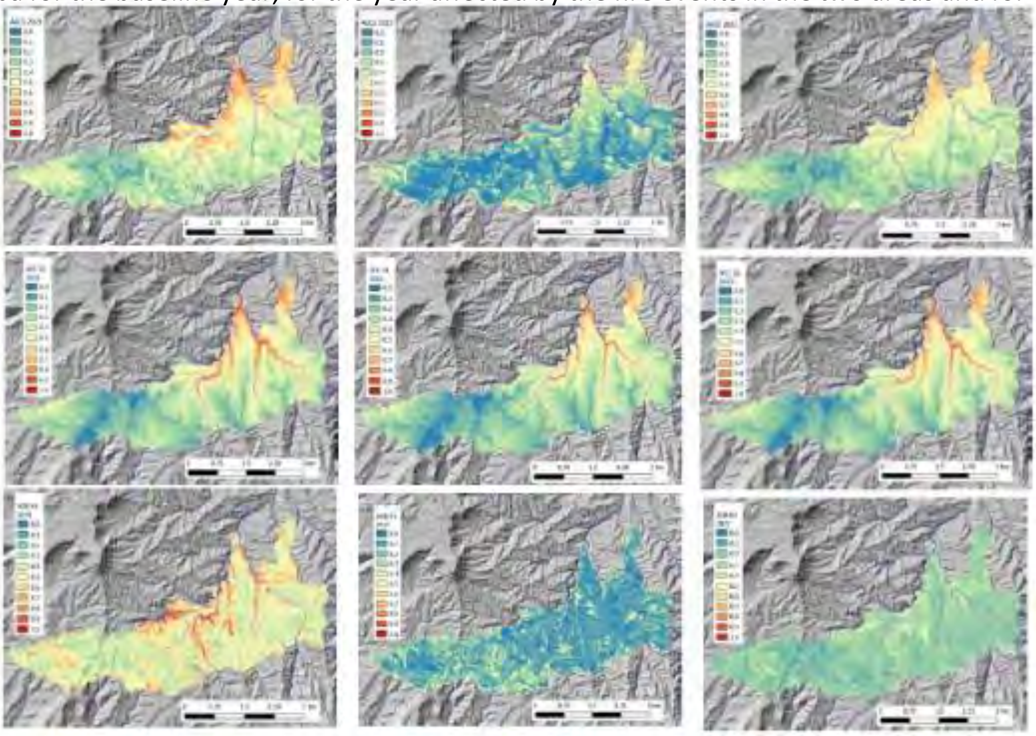

Figure 2. El Bruc: maps of the ES indicators (AGCS top, SEC middle, AGB bottom) for the baseline year 2019 (left), 2015 (centre) and 2022 (right).

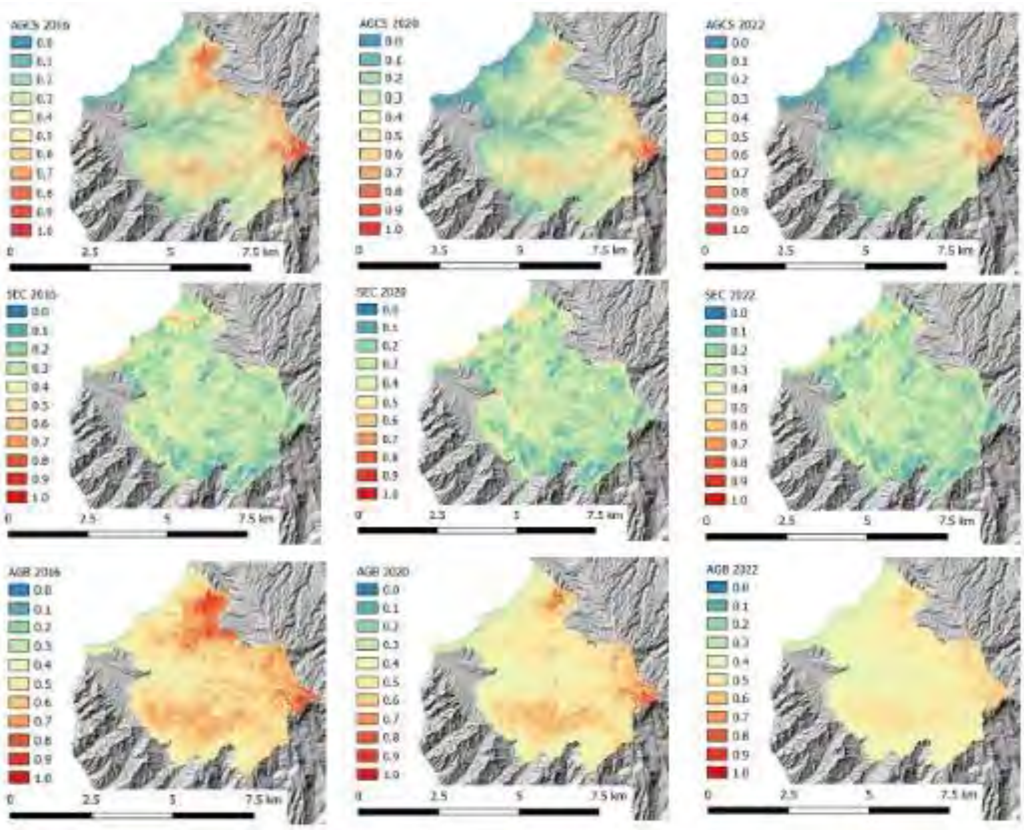

Figure 3. El Nublo II-Tamadaba: maps of the ES indicators (AGCS top, SEC middle, AGB bottom) for the baseline year 2016 (left), 2020 (centre) and 2022 (right).

In figures 2 and 3, green to blue colours indicate low ES provision, with the area in orange to red are those supplying high quality ES. The radar plots in figure 4 depict the annual variations in the three selected ESs supply with respect to the baseline years.

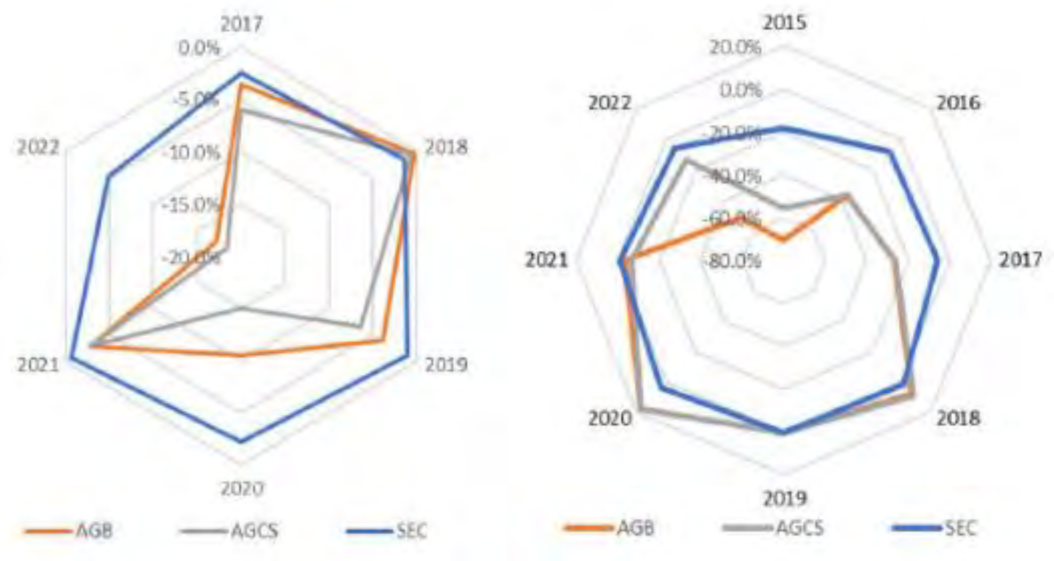

Figure 4. Relative annual variation in ES provision with reference to the selected baseline year (Left: El Nublo II-Tamadaba, right: El Bruc).

The proposed methodology has allowed to assess and map the values of three selected ES indicator along with their relative changes with respect to the baseline years. The integration of time dependent predictors from remote sensing in a spatially explicit digital mapping workflow has allowed to visualize where the changes occur and their relative magnitudes. The presented approach proved to be sensitive enough to depict negative changes in ES supply stemming from land degradation processes due to different drivers acting at different scales, such as wildfires and drought, but also positive changes due to ecosystem recovery. The results presented here detect yearly changes, but the approach can be easily tailored to finer temporal scales.

Acknowledgements

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References:

Haines-Young R., Potschin M., 2018. Common International Classification of Ecosystem Services, (CICES) V5.1. Guidance on the Application of the Revised Structure. Available at the follwing URL: https://cices.eu/content/uploads/sites/8/2018/01/Guidance-V51-01012018.pdf

Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., Moore, R., 2017. Google Earth Engine: Planetary-scale geospatial analysis for everyone. Remote Sensing of Environment.

Panagos, P., Van Liedekerke, M., Borrelli, P., Köninger, J., Ballabio, C., Orgiazzi, A., Lugato, E., Liakos, L., Hervas, J., Jones, A. Montanarella, L., 2022. European Soil Data Centre 2.0: Soil data and knowledge in support of the EU policies. European Journal of Soil Science, 73(6), e13315. DOI: 10.1111/ejss.13315

Rouse, J.W, Haas, R.H., Scheel, J.A., Deering, D.W., 1974. Monitoring Vegetation Systems in the Great Plains with ERTS. Proceedings, 3rd Earth Resource Technology Satellite (ERTS) Symposium, vol. 1, p. 48-62. https://ntrs.nasa.gov/citations/19740022614

Running, S., R. R. Nemani, F. A. Heinsch, M. Zhao, M. Reeves,H. Hashimoto. 2004. A continuous satellite-derived measure of global terrestrial primary production. BioScience, 54(6): 547-560. 2004.

Planting xerophytic shrubs significantly increased the carbon sequestration capacity and potential of sandy land

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Keywords: Keywords desertification land, xerophytic shrubs,climate warming, carbon storage, carbon sequestration potential

ABSTRACT
The process of desertification releases large amounts of carbon into the atmosphere, at present, deserts and desertification land area in Northern China is huge, which has caused serious damage to human existence and social and economic development, how to improve the carbon sequestration capacity of these areas is an important way to mitigate climate warming. In recent years, some xerophytic shrubs species have been used to control desertified land in many parts of north China. Carbon storage in typical sand-fixing vegetation areas (the ecological restoration area) after 20 and 30 years of planting xerophytic shrubs, respectively and the mobile sand dune were studied to assess whether planting xerophytic shrubs can improve the carbon sequestration capacity of sandy land. Field investigation were conducted, and soil and plant samples were analyzed in 2020. We found that planting suitable xerophytic shrubs in mobile sand area not only significantly increased vegetation carbon storage, but also significantly increased soil organic carbon storage. Compared with plant carbon density(0 $kg \cdot m^{-2}$) of mobile sand dune, after 20 and 30 years of planting xerophytic shrubs, plant carbon density in the ecological restoration area increased by 0.34 $kg \cdot m^{-2}$ and 0.27 $kg \cdot m^{-2}$, respectively. Compared with soil organic carbon density(0.39 $kg \cdot m^{-2}$) of mobile dune, after 20 and 30 years of planting xerophytic shrubs, soil organic carbon density increased by 0.28 $kg \cdot m^{-2}$ and 0.66 $kg \cdot m^{-2}$, respectively. Overall, the total organic carbon density increased by 1.58 and 2.34 times, respectively. And as time goes on, more organic carbon was stored in the soil, the proportion of soil organic carbon density reached 66.76% and 79.79% respectively after 20 and 30 years of planting xerophytic shrubs. Considering that xerophytic shrubs are mostly deep-rooted plants, which may transport more carbon to deep soil with ecosystem succession, and increase the carbon sequestration potential of vegetation restoration areas. Due to the huge area of deserts and desertification land in the world, our results suggest that reasonable planting of xerophytic shrubs on desertified land is an important management measure to mitigate climate warming.

Life-cycle environmental assessment of strategies for sewage treatment and reuse: a case study considering local conditions in south-central Chile

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Keywords: wastewater reuse; life-cycle assessment; circularity; resource recovery; water resources.

ABSTRACT

1. Introduction

During the last decades, the continuous increase in water demand, hydrological changes caused by climate change, and pollution of surface and groundwater sources have generated a widespread water crisis in the world. Water scarcity, understood as a situation where water demand exceeds available supply, has driven the search for alternative water sources that can help meet the current water demand, including rainwater harvesting, desalination of seawater/brackish water, and wastewater reuse. Wastewater reuse presents several advantages over other alternative water sources. Reclaimed water can be used for various purposes (such as irrigation, industrial processes, and potable consumption), and current technologies such as membrane processes ensure that the obtained water meets the quality requirements for supply. Furthermore, wastewater reuse has the advantage of being less dependent on hydrological conditions compared to alternatives such as water harvesting, and, in general, it has lower energy costs than seawater desalination processes. Currently, countries like Cyprus and Israel have widely implemented water reuse strategies for industrial and agricultural use, achieving reuse rates of over 80% (Vo et al., 2014). However, in regions where water scarcity is a new challenge, wastewater reuse is an incipient strategy, one that in the case of Chile has been proposed in several guidelines and governmental roadmaps that have been developed during the last decades to help confront the issue (e.g., DGA, 2016; MOP, 2012). However, and although the reduction of pollutant loads due to reuse can be a significant advantage of this strategy (Miller-Robbie et al., 2017), the implementation of treatment and distribution systems for water reuse is not free of social and environmental concerns. Some important environmental aspects include the civil works and building materials necessary for water treatment and distribution, and the energy and material inputs necessary for the treatment and distribution of wastewater (Lane et al., 2015).

In this scenario, the purpose of this study is to evaluate the environmental impacts associated with the implementation of different strategies for urban wastewater reuse in south-central Chile, using the Life Cycle Assessment (LCA) methodology. The study incorporates local conditions such as climate, wastewater characteristics, water demand, and the spatial location of end-users in the assessment, with a scope that includes the treatment of wastewater, its distribution to end-users, and the avoided impacts associated with the reduced pollutant loads discharged to aquatic ecosystems.

2. Materials and methods

2.1 Goal and scope definition

The objective of this study was to assess the environmental impacts associated with the implementation of wastewater reuse strategies, using the Ñuble region of Chile as a case study. The environmental performance of incorporating four urban wastewater reuse strategies in three cities was assessed. The Functional Unit (FU) defined for the analysis was the treatment and distribution of 1 m^3 of recovered water to the end user. The scope includes the requirements necessary for wastewater treatment (including the current technologies and the additional treatment to achieve water quality acceptable for reuse) and for

water transport to its final user. The four scenarios include: direct potable use (S_1), irrigation of green areas for direct-contact uses (S_2), non-contact agricultural irrigation (S_3), and non-food industrial use (S_4). A baseline scenario corresponding to the current situation was also included in the assessment (S_0). Three urban centres representing different conditions were selected for the analysis: Chillán, San Carlos, and Coelemu. Chillán is the regional capital with approximately 232,451 inhabitants, located in an area with significant agricultural and industrial activities. San Carlos, with a population close to 56,252, is one of the municipalities with the biggest agricultural activity in the region. Coelemu (18,788 inhab), on the other hand, represents a more rural settlement whose main economic activity is forestry.

The proposed treatment configurations for scenarios S_1 to S_4 were mainly based on the quality criteria established in international regulations for wastewater reuse (e.g., ISO 20761), a literature review performed by the authors about the currently used treatment technologies and configurations for water reuse (Riquelme et al., 2022), and the characteristics of local wastewater in terms of critical parameters to be removed for reuse, based on a statistical analysis of 6 years of operation.

2.2 Life cycle inventory

Both primary and secondary data were used for the construction of the life cycle inventories (LCI). Primary data was collected from the 17 wastewater treatment plants in the Ñuble region, including information on electricity, fuel, and chemical consumption, as well as emissions and solid waste generation. Secondary data from literature and databases (Ecoinvent 3.7, *cut-off* model) were utilized to complement the primary data. The LCI included the following stages:

<ins>Current wastewater treatment:</ins> Energy, fuels, and chemicals used in the current treatment processes were considered in this stage. The generation, treatment, and disposal of solid waste (including sludge and other wastes) were also included in the assessment, as well as the discharge of wastewater to receiving water bodies. <ins>Additional treatment for reuse</ins>: Infrastructure, energy and chemical consumption were considered in this stage, mainly from secondary sources. Processes included in the treatment configurations include multiple media filtration, membrane technologies, ozone, granular activated carbon (GAC), and disinfection, depending on the final use of water. <ins>Treated water distribution:</ins> Infrastructure and energy consumption associated with the distribution of wastewater to the final users was quantified based on the local conditions of the case studies. Use nodes and demand were determined based on official geospatial and statistical data (crop census, green spaces inventories, industrial records), and the material and energy requirements were estimated considering the vertical and horizontal distance from the treatment plant to the user nodes, and the corresponding reclaimed water flows. In S_1, S_3 and S_4, it was assumed that water transportation was performed through pipelines, while S_2 was based on the use of cistern (tanker) trucks.

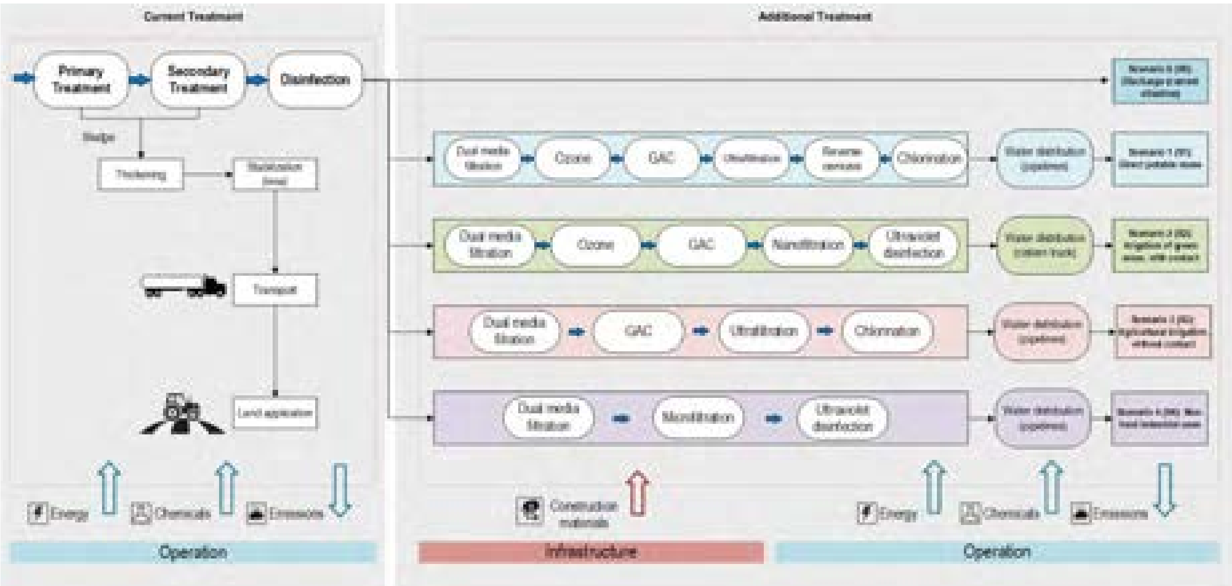

Figure 1. Graphical representation of the scope of the study

Air (N_2O and CH_4) and water (P and N) emissions associated with the discharge of non-reclaimed wastewater were also included in S_1, S_2, S_3 and S_4. Air emissions were estimated using the IPCC Tier 2 method, based on the characterisation of wastewater in the three case studies. Figure 1 resumes the full scope of the LCA foreground.

2.3 Impact assessment and interpretation of results

The ReCiPe 2016 midpoint method in his hierarchical version was used in the impact assessment step. Eight categories were included, mainly due to their relevance to the case study: climate change (CC); fossil resource scarcity (FRS); stratospheric ozone depletion (OD); terrestrial acidification (TA); terrestrial ecotoxicity (TEc); human toxicity, non-cancer effects (HTNC); freshwater eutrophication (FEu); and marine eutrophication (MEu). Interpretation of the results was performed mainly in terms of a comparison between the case studies and a contribution analysis. The variability of the characterized results was assessed through Monte Carlo simulation, with a fixed number of iterations (n=1000). All calculations were performed using the SimaPro 9.1 software.

3. Results and discussion

3.1 Current treatment systems

Figure 2 shows the environmental impact of the 17 current wastewater plants of the region for the eight assessed categories, and its relationship with its average treated flow.

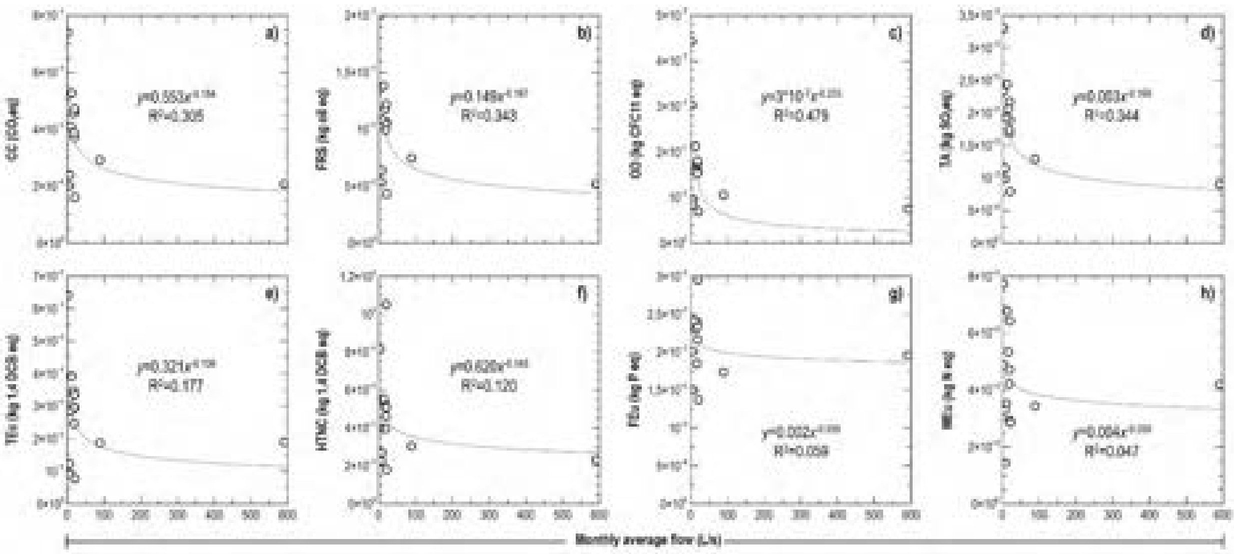

Figure 2. Results of impact characterization as a function of the monthly average flow of the 17 treatment plants of Ñuble. a) Climate Change, b) Fossil Resource Scarcity, c) Stratospheric Ozone Depletion, d) terrestrial Acidification, e) Terrestrial Ecotoxicity, f) Human Toxicity, Non-Cancer, g) Freshwater Eutrophication, h) Marine Eutrophication.

Overall, the results of the impact assessment are mainly associated with the energy consumption of the treatment processes. As the specific energy consumption was higher in smaller treatment plants (with three notable outliers in the plants of Pemuco, Santa Clara and San Ignacio), it resulted in the trend observed for most of the categories, excepting FEu and MEu. The highest contribution to these last categories is the water discharges from the plants, ranging from about 65 to 100% depending on the plant, which in turn are determined by the characterization of wastewater and treatment efficiency.

3.2 Wastewater reuse scenarios

Table 1 shows the characterized results for assessed scenarios in the three case studies.

Table 1. Summary of the reuse scenarios assessment. Colour goes from red to green to show the highest to the lowest environmental impacts, respectively.

Impact	Unit	Chillán				Coelemu				San Carlos			
		S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
CC	kg CO_{2eq}	1.59	8.44	0.54	0.33	1.36	4.68	0.49	0.19	1.40	3.63	0.44	0.19
OD	kg $CFC11_{eq}$ ($x10^{-6}$)	2.22	121.11	1.00	0.15	1.47	96.01	0.43	0.09	1.59	46.19	0.20	0.09
TA	kg SO_{2eq} ($x10^{-3}$)	8.01	13.54	2.62	1.72	6.91	6.33	2.48	0.98	7.08	7.10	2.26	0.98
FEu	kg P_{eq} ($x10^{-3}$)	2.12	164.04	1.35	0.22	0.97	87.41	0.59	0.13	1.28	92.47	0.27	0.13
MEu	kg N_{eq} ($x10^{-3}$)	2.88	412.55	2.62	0.02	0.37	261.14	0.91	0.01	1.33	294.33	0.02	0.01
TEc	kg 1,4-DCB_{eq}	7.62	60.46	2.54	1.71	6.53	11.80	2.40	0.98	6.70	16.98	2.19	0.98
HTNC	kg 1,4-DCB_{eq}	2.40	3.98	0.85	0.51	2.07	1.90	0.81	0.29	2.12	2.13	0.75	0.29
FRS	kg oil_{eq}	0.42	1.37	0.14	0.09	0.36	0.41	0.13	0.05	0.37	0.51	0.12	0.05

The highest impacts were obtained for all categories in the S_2 (green spaces irrigation) of Chillán, while the lowest were obtained in the S_4 (industrial use) of San Carlos. In the case of green spaces irrigation, the lower demand results in higher impacts associated with wastewater discharge to aquatic ecosystems, while industrial demand was able to take up all wastewater from the different case studies and avoid the impacts of its discharge. Furthermore, water transportation requirements can represent a significant environmental burden depending on the transportation method, distance, and differences in altitude, with the lowest impact observed when gravitational transport is possible (S_4). Finally, treatment requirements to comply with water quality can also be relevant for the results, as the higher intensity of treatments in S_1 and S_2 led to higher environmental impacts in this stage compared to S_3 and S_4.

4. Conclusion

This study aimed to evaluate the environmental impacts of wastewater reuse strategies considering the different life-cycle stages and including local conditions. The results mainly highlight the necessity of considering aspects such as wastewater quality requirements, the local demand of water uses, and geospatial information for the identification of environmentally friendly wastewater reuse practices. Recommendations based on the results of our analysis include: a) orientate reuse strategies to the applications with the highest overall demand, b) promote strategies that are concentrated and results in lower transportation requirements, and c) prioritize applications that demand lower water-quality standards, or treatment technologies with lower energy and material demands, such as constructed wetlands. It is expected that the findings could assist decision-makers in implementing effective and sustainable wastewater reuse practices.

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References:

1. DGA. 2016. *Atlas del Agua - Chile 2016*. Available at: http://www.dga.cl/DGADocumentos/Atlas2016parte1-17marzo2016b.pdf (in Spanish)
2. Lane, J. L., Haas, D. W. De, & Lant, P. A. 2015. The diverse environmental burden of city-scale urban water systems. *Water Research*, *81*, 398–415. https://doi.org/10.1016/j.watres.2015.03.005
3. Miller-Robbie, L., Ramaswami, A., & Amerasinghe, P. 2017. Wastewater treatment and reuse in urban agriculture: Exploring the food, energy, water, and health nexus in Hyderabad, India. *Environmental Research Letters*, *12*(7). https://doi.org/10.1088/1748-9326/aa6bfe
4. MOP. 2012. *Estrategia Nacional de Recursos Hídricos 2012 - 2025*. Available at https://www.mop.gob.cl/Carpeta/uploads/2021/04/Estrategia_Nacional_Recursos_Hidricos_DGA.pdf (in Spanish)
5. Riquelme, C., Gómez, G., Vidal, G., & Neumann, P. 2022. Critical analysis of the performance of pilot and industrial scale technologies for sewage reuse. *Journal of Environmental Chemical Engineering*, *10*(5). https://doi.org/10.1016/j.jece.2022.108198
6. Vo, P. T., Ngo, H. H., Guo, W., Zhou, J. L., Nguyen, P. D., Listowski, A., & Wang, X. C. 2014. A mini-review on the impacts of climate change on wastewater reclamation and reuse. *Science of the Total Environment*, *494–495*, 9–17. https://doi.org/10.1016/j.scitotenv.2014.06.090

The Ecological Engineering Nexus Accounting Framework: a tool for impact valuation of ecological engineering projects

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ABSTRACT

The current process of valuing and measuring the impact of ecological engineering initiatives faces limitations that hinder the comparison of costs and benefits across different projects and assessing their impact on a broader scale (Venkatachalam 2007; Gendron 2014). These limitations stem from a lack of consistency and standardization, making it challenging to evaluate the effectiveness of these projects in achieving sustainable outcomes. However, incorporating ecological and environmental economics into considering ecological engineering projects as new types of anthromes that can enable planetary health represents a crucial step toward sustainability (Mucina 2018).

Ecological engineering projects are inherently complex social-ecological systems that necessitate a nexus approach, integrating ecological, social, and economic dimensions to comprehensively evaluate their impact on the broader landscape (Venkatachalam 2007; Gendron 2014). To overcome these challenges, the Ecological Engineering Nexus Accounting Framework (EENAF) was developed and applied to three distinct types of nature-based solutions: constructed wetlands, floating treatment wetlands, and a regenerated natural wetland system, as ecological engineering approaches in South Africa. The EENAF methodology not only introduces a novel typology for nature-based systems within ecological engineering (Keith et al. 2020) but also incorporates a multi-scale integrated analysis of societal and ecosystem metabolism (MUSIASEM) bio-economic valuation (Giampietro et al. 2006) as an application of ecological engineering economics.

The EENAF framework represents a significant advancement in the field of ecological engineering by providing a comprehensive and standardized approach to assessing the impact of projects. By integrating ecological, social, and economic considerations, the framework ensures that all relevant factors are considered, leading to a more robust and accurate assessment of project outcomes. This innovative methodology sets a new standard for evaluating the effectiveness of ecological engineering initiatives, enabling policymakers, investors, and project developers to make informed decisions regarding these projects. The practical implications of the EENAF framework are vast, as it can potentially drive positive change and contribute to the development of sustainable solutions for environmental and societal challenges.

One of the primary contributions of the EENAF framework is its provision of a systematic and standardized approach for assessing the impact of ecological engineering projects on the environment, society, and economy. The study highlights the effectiveness of using standardized metrics such as the gross ecosystem product (GEP), industry value added linked to ecosystem services, monetary ecosystem asset value, and the cost of degradation to measure and evaluate the impact of these projects (UN 2021). By adopting these metrics, the EENAF framework allows for easy comparison and benchmarking across different projects and regions, enhancing scalability and replicability. This scalability enables broader framework adoption and facilitates knowledge sharing and collaboration among stakeholders, leading to more effective and efficient ecological engineering projects worldwide.

Moreover, the EENAF framework aligns with global sustainability goals, such as the United Nations Sustainable Development Goals (SDGs). Its focus on planetary health, sustainable outcomes, and economic viability reinforces its relevance in the context of international agendas. The framework's integration of ecological, social, and economic dimensions ensures that it addresses the interconnected and multifaceted nature of sustainability challenges, making it an ideal tool for supporting the achievement of SDGs and contributing to a more sustainable future.

In summary, the Ecological Engineering Nexus Accounting Framework (EENAF) makes a unique and significant contribution to the field of ecological engineering economics. It represents an innovative and multidisciplinary approach that sets a new standard for evaluating the effectiveness of ecological engineering initiatives, offering practical implications and real-world applications for policymakers, investors, and project developers. By bridging disciplinary boundaries, introducing novel typologies and metrics, and providing a holistic perspective, the framework advances the field and enhances our understanding of ecological engineering projects' economic viability and societal implications.

References

Gendron, C. (2014). Beyond environmental and ecological economics: Proposal for an economic sociology of the environment. Ecological Economics, 105, 240-253.

Giampietro, M., Mayumi, K., & Ramos-Martin, J. (2006). Mult-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MUSIASEM): An outline of rationale and theory. Presented at the 5th Biennial International Workshop Advances in Energy Studies, "Perspectives on Energy Future," held in Porto Venere, Italy, 12 - 16 September 2006.

Keith, D. A., Ferrer-Paris, J. R., Nicholson, E., & Kingsford, R. T. (Eds.). (2020). The IUCN Global Ecosystem Typology 2.0: Descriptive profiles for biomes and ecosystem functional groups. Gland, Switzerland: IUCN.

Mucina, L. (2018). Biome: evolution of a crucial ecological and biogeographical concept. New Phytologist, 222, 97–114. doi:10.1111/nph.15609.

Porras, I., & Steele, P. (2020). Making the market work for nature. How biocredits can protect biodiversity and reduce poverty. IIED Issue Paper. IIED, London.

United Nations (UN). (2021). System of Environmental-Economic Accounting – Ecosystem Accounting (SEEA EA). White cover publication, pre-edited text subject to official editing. UN.

Venkatachalam, L. (2007). Environmental economics and ecological economics: Where can they converge? Ecological Economics, 61, 550-558.

Nature-based and solar energy building solutions in the water-energy-food nexus across diverse climatic zones in Europe

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Keywords: Built environment, carbon-neutral cities, carbon-neutral regions, climate change, mitigation, nature-based solutions, renewables, resilience

ABSTRACT

Nature-based and solar energy building solutions play a crucial role in addressing the complex interconnections of the water-energy-food (WEF) nexus, particularly in the face of climate change (Albrecht et al., 2018; Zhang et al., 2018; Li et al., 2019; Bayulken et al. 2021; Sowińska-Świerkosz et al. 2022). The transition to clean energy and the decarbonization of our built environment require innovative approaches that holistically consider the interplay between water, energy, and food systems. In this regard, the synergistic integration of solar energy technologies, such as thermal systems and photovoltaics (PV/T) (Chen et al., 2022; Skandalos et al., 2022), with nature-based solutions (NBS) including green roofs and green walls has emerged as a promising strategy to promote urban resilience and sustainability (Liu et al., 2023). By integrating NBS and solar energy systems within the built environment, it becomes possible to create synergistic solutions that address multiple dimensions of the WEF nexus. This integration can enhance water management, reduce energy consumption and emissions, and support sustainable food production in urban areas (Li et al, 2019; Hayes et al, 2022). Moreover, the combination of NBS and solar energy in the built environment contributes to the overall resilience, sustainability, and carbon neutrality of cities and regions (Liu et al., 2023).

To unlock the full potential of the synergies between NBS and solar energy technologies, it is crucial to establish a generalized framework that considers shared resources and their interactions with other functions and our biodiverse environment (Fig. 1). The link between NBS and solar energy in the built environment can be established by considering their interconnectedness within the WEF nexus. There are several ways in which NBS and solar energy can be linked within this framework:

1) Water: NBS, such as green roofs and green walls, can contribute to water management within the built environment (Raymond et al., 2017; Lafortezza et al., 2018; Bush et al., 2019; Colléony et al., 2019; Liu et al, 2021; Pietneda-Pinto et al., 2022; Calliari et al, 2022). Water resources sustainability, especially within the built environment, are expected to be challenged due to urban sprawl, population growth and climate change (Kourtis et al., 2021). NBS pose a sustainable way forward as they have the potential to capture and retain rainwater, reducing reduce stormwater runoff and, alleviating alleviate pressure on water resources, improve water quality and offer ecosystem services (e.g., reduced energy demand of buildings, visual amenity, etc). Solar energy systems, on the other hand, can power water pumps and filtration systems, enhancing water availability and quality for various uses within the built environment.

2) Energy: Solar energy technologies, such as photovoltaic (PV) panels and solar thermal systems, generate clean and renewable energy (Maghrabie et al., 2021; Izam et al., 2022; Skandalos et al., 2022). By

integrating solar energy systems into buildings and urban infrastructure, the energy demand from traditional sources can be reduced. This, in turn, contributes to the mitigation of greenhouse gas (GHG) emissions and the overall sustainability of the energy sector. Additionally, NBS can provide shading and cooling effects, reducing the energy consumption for air conditioning, and improving thermal comfort in buildings.

3) Food: NBS can play a vital role in urban agriculture and food production. Rooftop gardens, vertical farming, and urban green spaces provide opportunities for cultivating food within the built environment. By integrating NBS with solar energy systems, energy requirements for lighting, irrigation, and climate control in indoor farming can be met sustainably (Carvalho et al., 2022). Solar energy can power artificial lighting systems and provide energy for greenhouse operations, supporting year-round food production and reducing dependence on non-renewable energy sources.

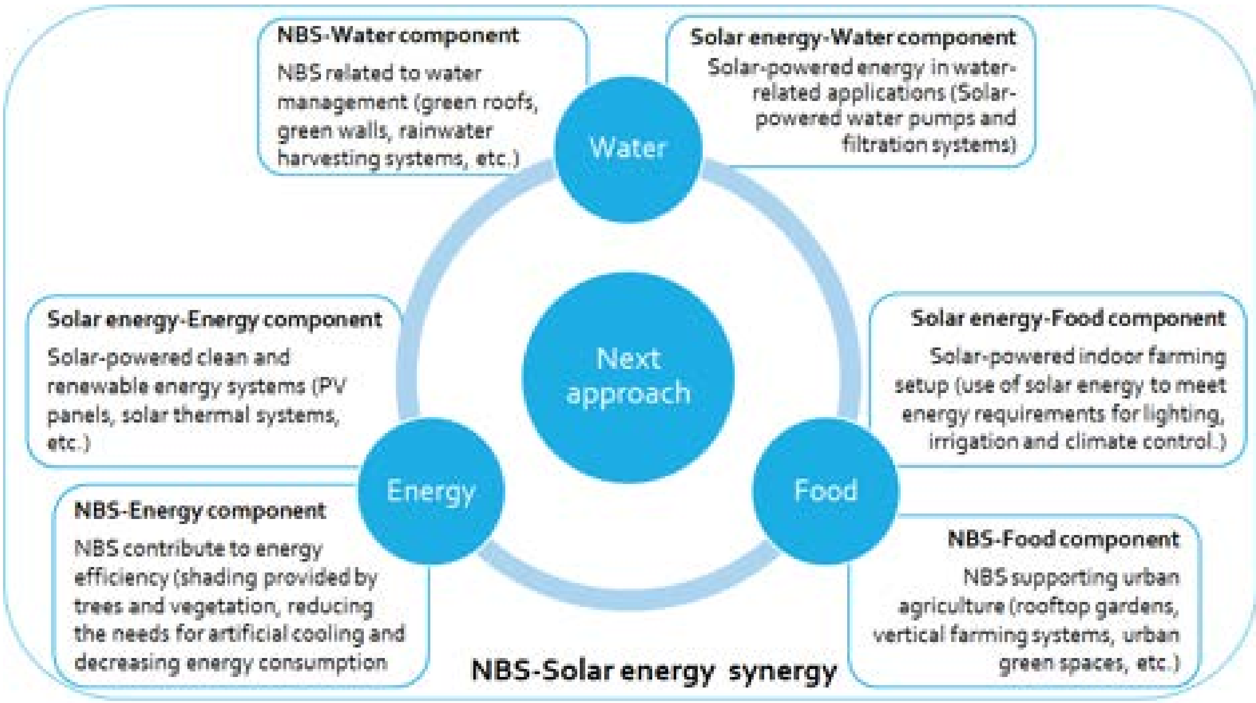

Figure 29. Integrated approach: connected NBS, solar energy, and the water-energy-food nexus in the built environment.

By harnessing the collective benefits of these solutions, it becomes possible to achieve multiple co-benefits across the WEF nexus. For instance, green roofs and green walls provide numerous ecosystem services, such as improved air quality, reduced urban heat island (UHI) effect, stormwater management, and enhanced biodiversity. Simultaneously, solar energy technologies, particularly PV/T systems, generate renewable energy while effectively utilizing building surfaces. Integrating these solutions within a holistic framework (Fig. 1) can optimize their benefits and contribute to the overall sustainability and resilience of urban areas.

In this study, to evaluate the effectiveness of the NBS-PV/T synergy, a comprehensive literature review was conducted. The study focused on four representative European cities, chosen to encompass diverse climatic zones based on the extended Koppen-Geiger-GHI classification scheme. By analyzing the findings from previous studies, the outcomes of integrating NBS and PV/T were evaluated, and opportunities for best practices were identified.

The results of this study demonstrate that the integration of NBS and PV/T can yield positive outcomes for the built environment within the WEF nexus. The combination of greenery and solar energy technologies has the potential to enhance urban sustainability and resilience across different climatic zones in Europe.

The benefits encompass various aspects, including energy generation, reduction of carbon emissions, improved thermal comfort, increased food production, enhanced water management, and heightened biodiversity. Furthermore, the implementation of NBS-PV/T solutions can contribute to the creation of carbon-neutral cities and regions, thereby advancing the global efforts to mitigate climate change and achieve sustainable development goals (SDGs).

The most relevant SDGs that are addressed by the integration of nature-based and solar energy building solutions in the WEF nexus are i) SDG 7: Affordable and Clean Energy - By integrating solar energy systems, such as PV and solar thermal systems, renewable and clean energy sources are utilized, contributing to the goal of ensuring access to affordable, reliable, sustainable, and modern energy for all; 2) SDG 11: Sustainable Cities and Communities - The integration of NBS and solar energy technologies in the built environment promotes sustainable urban development, enhances urban resilience, and contributes to the creation of carbon-neutral cities. This aligns with the goal of making cities and human settlements inclusive, safe, resilient, and sustainable; 3) SDG 13: Climate Action - The combination of NBS and solar energy contributes to mitigating climate change by reducing GHG emissions, promoting energy efficiency, and fostering the transition to renewable energy sources; 4) SDG 15: Life on Land - NBS, such as green roofs, green walls, and urban green spaces, contribute to the preservation and restoration of ecosystems and biodiversity within urban areas, supporting the goal of protecting, restoring, and promoting sustainable use of terrestrial ecosystems; and 5) SDG 12: Responsible Consumption and Production - The integration of nature-based and solar energy solutions promotes sustainable consumption and production patterns by reducing energy consumption, utilizing renewable energy sources, and supporting sustainable food production through urban agriculture and local food systems. These SDGs highlight the multidimensional benefits and positive impacts of integrating nature-based and solar energy building solutions in the WEF nexus, demonstrating their alignment with the broader sustainable development agenda.

This study underscores the importance of adopting an integrated and holistic approach to address the interconnected challenges of water, energy, and food in the built environment. It highlights the importance of considering the intricate relationships within the WEF nexus and the broader environmental context when implementing nature-based and solar energy building solutions. This approach maximizes the co-benefits and synergies between NBS and solar energy systems, promoting sustainable and resilient urban development. By optimizing the combination of NBS and PV/T within a holistic framework, valuable insights can be gained for policymakers, urban planners, and architects in their efforts to design sustainable and resilient cities. Moreover, the identified best practices can serve as a guiding framework for future research, enabling the development of innovative solutions that effectively address the challenges of the WEF nexus and accelerate the adoption of renewable energy sources.

References:

Albrecht, T.R., Crootof, A., Scott, C.A, 2018. The Water-Energy-Food Nexus: A systematic review of methods for nexus assessment. Environmental Research Letters 13, 4.

Bayulken, B., Huisingh, D., Fisher, P.M.J., 2021. How are nature-based solutions helping in the greening of cities in the context of crises such as climate change and pandemics? A comprehensive review. Journal of Cleaner Production 288, 125569.

Bush, J., Doyon, A., 2019. Building urban resilience with nature-based solutions: How can urban planning contribute? Cities 95, 102483.

Calliari, E., Castellari, S., Davis, M., Linnerooth-Bayer, J., Martin, J., Mysiak, J., Pastor, T., Ramieri, E., Scolobig, A., Sterk, M., Veerkamp, C., Wendling, L., Zandersen M., 2022. Building climate resilience through nature-based solutions in Europe: A review of enabling knowledge, finance and governance frameworks. Climate Risk Management 37, 100450.

Carvalho, P.N., Finger, D.C., Masi, F., Cipolletta, G., Oral, H.V., Tóth, A., Regelsberger, M., Exposito, A., 2022. Nature-based solutions addressing the water-energy-food nexus: Review of theoretical concepts and urban case studies. Journal of Cleaner Production 338, 130652.

Chen, T., An, Y., Heng, C.K., 2022. A Review of building-integrated photovoltaics in Singapore: status, barriers, and prospects. Sustainability 14, 10160.

Colléony A., Shwartz A., 2019. Beyond assuming co-benefits in nature-based solutions: A human-centered approach to optimize social and ecological outcomes for advancing sustainable urban planning. Sustainability 11(18),4924.

Hayes, A.T., Jandaghian, Z., Lacasse, M.A., Gaur, A., Lu, H., Laouadi, A., Ge, H., Wang, L., 2022. Nature-based solutions (NBSs) to mitigate urban heat island (UHI) effects in canadian cities. Buildings 12(7), 925.

Izam, N.S.M.N., Itam, Z., Sing, W.L., Syamsir, A., 2022. Sustainable development perspectives of solar energy technologies with focus on solar photovoltaic—A Review. Energies 15(8), 2790.

Kourtis, I.M., Bellos, V., Kopsiaftis, G., Psiloglou, B., Tsihrintzis, V.A., 2021. Methodology for holistic assessment of grey-green flood mitigation measures for climate change adaptation in urban basins. Journal of Hydrology 603, 126885.

Lafortezza, R., Chen, J., van den Bosch, C.K., Randrup, T.B., 2018. Nature-based solutions for resilient landscapes and cities. Environmental Research 165, 431-441.

Li, G., Wang, Y., Li, Y., 2019. Synergies within the Water-Energy-Food Nexus to support the integrated urban resources governance. Water 11(11), 2365.

Liu, H.-Y., Jay, M., Chen, X. 2021. The role of nature-based solutions for improving environmental quality, health and well-being. Sustainability 13, 10950.

Liu, H.-Y., Skandalos, N., Braslina, L., Kapsalis, V., Karamanis, D., 2023. Integrating solar energy and nature-based solutions for climate-neutral urban environments. Solar 3, 382-415.

Maghrabie, H.M., Elsaid, K., Sayed, E.T., Abdelkareem, M.A., Wilberforce, T., Olabi. A.G., 2021. Building-integrated photovoltaic/thermal (BIPVT) systems: Applications and challenges. Sustainable Energy Technologies and Assessments 45, 101151.

Pineda-Pinto, M., Frantzeskaki, N., Nygaard, C.A., 2022. The potential of nature-based solutions to deliver ecologically just cities: Lessons for research and urban planning from a systematic literature review. Ambio 51, 167–182.

Raymond, C.M., Frantzeskaki, N., Kabisch, N., Berry, P., Breil, M., Nita, MR., Geneletti, D., Calfapietra. C., 2017. A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. Environmental Science & Policy 77, 15-24.

Skandalos, N., Wang, M., Kapsalis, V., D'Agostino, D., Parker, D., Bhuvad, S.S., Udayraj, Peng, J., Karamanis, D., 2022. Building PV integration according to regional climate conditions: BIPV regional adaptability extending Köppen-Geiger climate classification against urban and climate-related temperature increases. Renewable and Sustainable Energy Reviews 169, 112950.

Sowińska-Świerkosz, B., García, J., 2022. What are Nature-based solutions (NBS)? Setting core ideas for concept clarification. Nature-Based Solutions 2, 100009.

Zhang, C., Chen, C.X., Li, Y., Ding, W., Fu, G., 2018. Water-energy-food nexus: Concepts, questions and methodologies. Journal of Cleaner Production 195, 625-639.

Assessment of Carbon Sequestration Potential of Targeted Plants Using Remote Sensing, GIS, and Machine Learning Systems

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Keywords: Biomass, Carbon sequestration, Climate change, Allometric equation, Vegetation indices

ABSTRACT

Climate change represents the most significant environmental threat of the 21st century to the planet. The primary driver behind the current rapid pace of climate change is attributed to human activities, particularly the emission of greenhouse gases, with carbon dioxide (CO2) being the main culprit. To effectively mitigate climate change, it is widely recognized that reducing carbon emissions and enhancing carbon sequestration can be accomplished by safeguarding and conserving carbon stocks in existing forests.

Accurately assessing the quantity of above-ground woody biomass is of utmost importance in the context of sustainable forest management and gaining insights into the role of forests as carbon sources or sinks. Enhancing the accuracy of biomass assessment can be achieved by developing predictive equations based on locally gathered data. In plants resource assessment, remote sensing (RS) techniques have gained popularity due to their ability to cover large areas in a cost-effective manner, even with limited field data. However, the absence of localized biomass equations and the uncertainty associated with utilizing existing regional or global equations prompted this study to focus on developing equations for biomass and carbon sequestration on a tree-by-tree basis in the high temperate forest of Oman.

To estimate the biomass on targeted trees, a "destructive method" was employed, wherein the trees were harvested in the field. These sample trees served as the foundation for developing the biomass equations. This method proved to be reliable and unaffected by variations in branching patterns and tree species. Three types of biomass equations were formulated. The results of our investigation demonstrate that the targeted plant species possesses a notable capacity for carbon sequestration. Our analysis of aboveground biomass measurements and carbon stock calculations revealed that Prosopis cineraria (Druce) can sequester an average of 197.1 kilograms of carbon per tree, while Phragmites australis (Mangrove) can sequester an average of 12.4 kilograms of carbon per tree. Additionally, Phragmites australis (reed grass) exhibited an average carbon sequestration rate ranging from 2.2 to 1.0 kilograms per square meter. Although the absolute values obtained in our study were within the range observed for similar plant species, they align with findings reported in various global studies.

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References:

Al-Nadabi, A. S., & Sulaiman, H. (2021). Carbon Sequestration Service of a Ramsar Site: A Conservation-Role Model for Defying Developmental Pressure in the Middle of a Rapidly Expanding City. Open Journal of Forestry, 11(4), 381-397.

Al-Guwaiz, S. M., Alatar, A. A., El-Sheikh, M. A., Al-Gehni, G. A., Faisal, M., Qahtan, A. A., & Abdel-Salam, E. M. (2021). Role of mangrove rehabilitation and protection plans on carbon storage in Yanbu industrial city, Saudi Arabia: A case study. Sustainability, 13(23), 13149.

Adame, M. F., Santini, N. S., Tovilla, C., Vázquez-Lule, A., Castro, L., & Guevara, M. (2015). Carbon stocks and soil sequestration rates of tropical riverine wetlands. Biogeosciences, 12(12), 3805-3818. https://doi.org/10.5194/bg-12-3805-2015;

Archana, V., Tewari, J. C., Ram, P., & Shalander, K. (2015). Carbon stock of woody vegetation in hot arid region of Rajasthan. International Journal of Tropical Agriculture, 33(4 (Part II)), 3019-3023.

Alsumaiti, T. S. S. (2014). Structure, Aboveground Biomass, and Soil Characterization of Avicennia marina in Eastern Mangrove Lagoon National Park, Abu Dhabi. University of Arkansas.

Barati, S., Rayegani, B., Saati, M., Sharifi, A., & Nasri, M. (2011). Comparison the accuracies of different spectral indices for estimation of vegetation cover fraction in sparse vegetated areas. The Egyptian Journal of Remote Sensing and Space Science, 14(1), 49-56.

Byrd, K. B., O'Connell, J. L., Di Tommaso, S., & Kelly, M. (2014). Evaluation of sensor types and environmental controls on mapping biomass of coastal marsh emergent vegetation. Remote Sensing of Environment, 149, 166-180.

Cairns, M.A., Olmsted, I., Granados, J. and Argaez, J., 2003. Composition and aboveground tree biomass of a dry semi-evergreen forest on Mexico's Yucatan Peninsula. Forest Ecology and Management, 186(1-3): 125-132.

C. O. Iglesias, "Determination of carbon sequestration and storage capacity of eucalyptus plantation in Sra Kaew Province," Thailand using remote sensing, MSc Thesis, Mahidol University, Thailand (2007).

Chambers, J.Q., J. Santos, R.J. Ribeiro & N. Higuchi. 2001. Tree damage, allometric relationships, and above-ground net primary production in a tropical forest. Forest Ecology and Management. 152: 73-84.

Chave, J., A. Andalo, S. Brown, M.A. Cairns, J.Q. Chambers, D. Eamus, H. Fölster, F. Fromard, N. Higuchi, T. Kira, J.-P. Lescure, B.W. Nelson, B.W., H. Ogawa, H. Puig, B. Riéra, T. Yamakura. 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oceologia 145: 87-99.

Cole, T.G. & J.J. Ewel. 2006. Allometric equations for four valuable tropical tree species. Forest Ecology and Management 229: 351-360

Conti, G., Gorne, L. D., Zeballos, S. R., Lipoma, M. L., Gatica, G., Kowaljow, E., ... & Fernandes, P. M. (2019). Developing allometric models to predict the individual aboveground biomass of shrubs worldwide. Global Ecology and Biogeography, 28(7), 961-975.

Clough, B. F., Dixon, P., & Dalhaus, O. (1997). Allometric relationships for estimating biomass in multi-stemmed mangrove trees. Australian Journal of Botany, 45(6), 1023-1031.

Goslee, K., Walker, S. M., Grais, A., Murray, L., Casarim, F., & Brown, S. (2016). Module C-CS: calculations for estimating carbon stocks. Leaf technical guidance series for the development of a forest carbon monitoring system for REDD.

cr.usgs.gov/appeears〉. Aspinall, S., 2001. Environmental development and protection in the UAE. United Arab Emirates: A New Perspective, p. 278.

Chen, C., Ma, Y., Ren, G., & Wang, J. (2022). Aboveground biomass of salt-marsh vegetation in coastal wetlands: Sample expansion of in situ hyperspectral and Sentinel-2 data using a generative adversarial network. Remote Sensing of Environment, 270, 112885.

Comley, B. W., & McGuinness, K. A. (2005). Above-and below-ground biomass, and allometry, of four common northern Australian mangroves. Australian Journal of Botany, 53(5), 431-436.

Dai, X., Yang, G., Liu, D., & Wan, R. (2020). Vegetation carbon sequestration mapping in herbaceous wetlands by using a MODIS EVI time-series data set: a case in Poyang lake wetland, China. Remote Sensing, 12(18), 3000.

Dong, W., Shu, J., He, P., Ma, G., & Dong, M. (2012). Study on the carbon storage and fixation of phramites autralis in Baiyangdian demonstration area. Procedia Environmental Sciences, 13, 324-330.

Duke, N., Nagelkerken, I., Agardy, T., Wells, S. and Van Lavieren, H., 2014. The importance of mangroves to people: a call to action. United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC).

Dai, M., Liu, D., Liu, M., Zhou, F., Li, G., Chen, Z., ... & Cai, H. (2020). Patients with cancer appear more vulnerable to SARS-CoV-2: A multicenter study during the COVID-19 outbreakpatients with cancer in SARS-COV-2 infection. Cancer discovery, 10(6), 783-791.

Japan International Cooperation Agency (JICA)& Ministry of Environment and Climatic Affairs (MECA). (2004). The Master Plan Study on Restoration, Conservation and Management of Mangrove in the Sultanate of Oman. Vol (2). Pacific Consultants International& Appropriate Agriculture International Co., Ltd.

FAO. 2005. Kyoto Protocol - important tool for sustainable development http://www.fao.org/newsroom/en/news/2005/89781/index.html;

FAO. 2008. Terrestrial Essential Climate Variables for Climate Change Assessment, Mitigation and Adaptation [GTOS 52] http://www.fao.org/gtos/doc/pub52.pdf

IPCC. 2006. IPCC Guidelines for National Greenhouse Gas Inventories. Prepared by The National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia, L., Miwa, K., Ngara, T. and Tanabe, K. (eds.). Published by IGES Japan.

IPCC. (2014). Climate Change, I. C. (2014). Mitigation of climate change. Contribution of working group III to the fifth assessment report of the intergovernmental panel on climate change, 1454, 147.

Allometric models for estimating above- and below-ground biomass in Amazonian forests at São Gabriel da Cachoeira in the upper Rio Negro, Brazil. Forest Ecology and Management 277: 163-172. http://dx.doi.org/10.1016/j.foreco.2012.04.028

Walker, S. M., Murray, L., & Tepe, T. (2016). Allometric equation evaluation guidance document. Winrock International, USA.

Remote sensing-based water quality inversion in Třeboň fishponds: a comparative analysis of machine learning algorithms

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Keywords: Fishponds, Machine learning, Remote sensing, Water quality inversion

ABSTRACT

Třeboň fishpond system is a collection of over five hundred fishponds that are shallow water bodies that started in Central Europe in the Middle Ages. They continue to be used for aquaculture, flood management, recreation, and biodiversity protection and are currently listed on the UNESCO World Heritage Tentative List as an important Czech cultural site. There has been a dramatic decrease of those fishponds from 180,000 hectares to 52,000 hectares from the 16th century to now. Meantime, the intensive human activities (drainage, sewage discharge, and intensification of fish production) resulted in water eutrophication and augmentation of natural fish production.

Remote sensing is a powerful tool for monitoring water quality as data can be collected rapidly, across a wide area, at low cost, and at regular periods. Monitoring water quality by remote sensing depends on establishing relationships between the concentration of water constituents and the observed spectral reflectance. This is commonly done by using empirical (Zhou et al., 2017), analytical (Wu et al., 2011), and semiempirical methods (Jiang et al., 2010; T. Wang et al., 2008). Empirical methods allow water quality to be retrieved using different statistical regression models built based on the statistical characteristics of spectral data and the measured water quality. Analytical methods allow water quality information to be obtained based solely on the radiative transport model of water. The transport model is obtained by simultaneously considering the spectral characteristics of the components in water and their relationship to the absorption and backscattering coefficient of each component. Semi-empirical methods estimate water quality parameters using the statistical relationship between the suitable wavebands and the measured water quality parameters, such as bio-optical models (Li et al., 2010). The deep learning method is a semi-empirical method that has been heavily researched in recent years (Peterson et al., 2020).

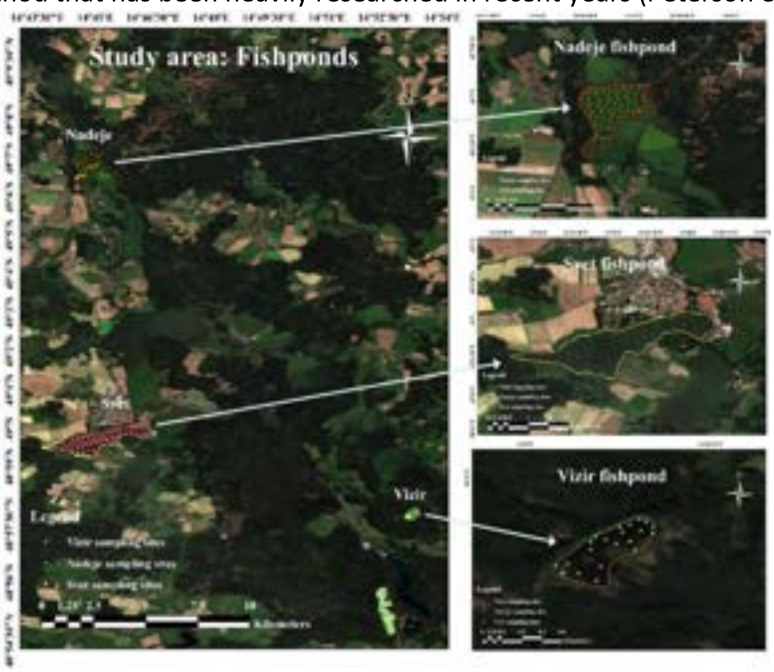

Fig 1. Location of three fishponds and sampling points.

This study intended to use the remote sensing image interpretation to inverse the water quality of the fishponds with different fish stock density, thus, two linear model algorithm and two machine learning algorithms were compared to select the best algorithms for better prediction of cyanobacteria and total microalgae.

Three fishponds (Svět, Naděje, and Vizír) were selected for water quality monitoring based on their fish stock density. Two sampling campaigns already carried out in Summer and Autumn. The location of fishponds and sampling points are given in Figure 1.

The correlation of cyanobacteria and total microalgae concentration with four bands from Sentinel-2 was carried out by Pearson analysis. Band 2-Blue, Band 3-Green, Band 4-Red, Band 8-NIR.

Table 1. Pearson correlation coefficient analysis in Svět (moderate fish stock density, n=114), ** Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed).

Correlations	Cyanobacteria	Total Algae	B2	B3	B4	B8
Cyanobacteria	1	.822**	0.043	-.281**	-0.057	-0.036
Total Algae	.822**	1	0.129	-.223*	0.048	0.072
B2	0.043	0.129	1	.682**	.833**	.472**
B3	-.281**	-.223*	.682**	1	.778**	.341**
B4	-0.057	0.048	.833**	.778**	1	.645**
B8	-0.036	0.072	.472**	.341**	.645**	1

Table 2. Pearson correlation coefficient analysis in Naděje (high fish stock density, n=92).

Correlations	Cyanobacteria	Total Algae	B2	B3	B4	B8
Cyanobacteria	1	.986**	.364**	.288**	.273**	.340**
Total Algae	.986**	1	.392**	.335**	.309**	.388**
B2	.364**	.392**	1	.697**	.831**	.522**
B3	.288**	.335**	.697**	1	.793**	.503**
B4	.273**	.309**	.831**	.793**	1	.514**
B8	.340**	.388**	.522**	.503**	.514**	1

Table 3. Pearson correlation coefficient analysis in Vizír (low fish stock density, n=22).

Correlations	Cyanobacteria	Total Algae	B2	B3	B4	B8
Cyanobacteria	1	.798**	.446*	0.368	.590**	0.228
Total Algae	.798**	1	.564**	.549**	.688**	0.39
B2	.446*	.564**	1	.941**	.915**	.887**
B3	0.368	.549**	.941**	1	.862**	.911**
B4	.590**	.688**	.915**	.862**	1	.685**
B8	0.228	0.39	.887**	.911**	.685**	1

Table 4. Pearson correlation coefficient analysis in Svět and Naděje (n=206).

Correlations	Cyanobacteria	Total Algae	B2	B3	B4	B8
Cyanobacteria	1	.882**	.175*	.472**	.337**	.414**
Total Algae	.882**	1	.227**	.289**	.298**	.369**
B2	.175*	.227**	1	.495**	.773**	.389**
B3	.472**	.289**	.495**	1	.756**	.504**
B4	.337**	.298**	.773**	.756**	1	.569**
B8	.414**	.369**	.389**	.504**	.569**	1

Four models namely sparse multinomial logistic regression (SMLR), partial least squares regression (PLSR), support vector machine (SVM), and Random Forest (RF) were established to predict cyanobacteria concentration from Sentinel-2 images, results are shown in Table 5. The training set was set with 70% data, and validation set was set with 30% data. The results show that SVM is the best model for cyanobacteria prediction with the R^2 of 0.65 and 0.63 for the training and test set, respectively.

Table 5. Four models establishment for Cyanobacteria prediction.

Models	Data sources	Training set			Validation set		
		R^2	RMSE	RPD	R^2	RMSE	RPD
SMLR	Svět	0.20	17.01	1.12	0.39	14.63	1.30
	Naděje	0.25	20.18	1.16	0.23	17.89	1.16
	Vizír	0.15	0.16	1.12	0.84	0.14	2.70
	Svět+Naděje	0.29	25.51	1.19	0.48	19.07	1.39
	Svět+Naděje+Vizír	0.65	33.22	1.71	0.56	27.16	1.52
PLSR	Svět	0.20	17.01	1.12	0.39	14.63	1.30
	Naděje	0.25	20.18	1.16	0.23	17.89	1.16
	Vizír	0.15	0.16	1.12	0.84	0.14	2.70
	Svět+Naděje	0.29	25.51	1.19	0.48	19.07	1.39
	Svět+Naděje+Vizír	0.65	33.22	1.71	0.56	27.16	1.52
SVM	Svět	0.18	17.44	1.10	0.43	14.38	1.32
	Naděje	0.32	19.33	1.21	0.33	17.26	1.20
	Vizír	0.15	0.16	1.09	0.60	0.25	1.56
	Svět+Naděje	0.34	24.60	1.23	0.76	7.42	1.57
	Svět+Naděje+Vizír	0.65	33.87	1.67	0.63	25.17	1.64
RF	Svět	0.06	18.49	1.03	0.04	18.75	1.01
	Naděje	0.14	21.77	1.08	0.00	22.13	0.94
	Vizír	0.07	0.20	0.88	0.63	0.42	0.92
	Svět+Naděje	0.31	25.15	1.21	0.28	22.70	1.17

	Svět+Naděje+Vizír	0.60	35.93	1.58	0.52	28.90	1.43

Acknowledgements

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References:

Jiang, G., Liu, D., Song, K., Xu, J., Zhang, B., & Wang, Z. (2010). Estimation of Total Suspended Matter Concentration in Shitoukoumen Reservoir Based on a Semi-empirical Model. Remote Sensing Technology and Application, 25, 107–111.

Li, L., Li, L., & Song, K. (2010). A bio-optical approach to estimating chlorophyll-a concentration from hyperspectral remote sensing. SPIE Proceedings, 7809. https://doi.org/10.1117/12.859484

Peterson, K. T., Sagan, V., & Sloan, J. J. (2020). Deep learning-based water quality estimation and anomaly detection using Landsat-8/Sentinel-2 virtual constellation and cloud computing. GIScience & Remote Sensing, 57(4), 510–525. https://doi.org/10.1080/15481603.2020.1738061

Wang, T., Tan, C., Chen, L., & Tsai, Y. (2008). Applying artificial neural networks and remote sensing to estimate chlorophyll-a concentration in water body. Proceedings - 2008 2nd International Symposium on Intelligent Information Technology Application, IITA 2008, 1, 540–544. https://doi.org/10.1109/IITA.2008.279

Wu, G., Cui, L., Duan, H., Fei, T., & Liu, Y. (2011). Absorption and backscattering coefficients and their relations to water constituents of Poyang Lake, China. Applied Optics, 50(34), 6358–6368. https://doi.org/10.1364/AO.50.006358

Zhou, X., Marani, M., Albertson, J. D., & Silvestri, S. (2017). Hyperspectral and multispectral retrieval of suspended sediment in shallow coastal waters using semi-analytical and empirical methods. Remote Sensing, 9(4). https://doi.org/10.3390/rs9040393

Session C4: Constructed wetlands technology II

A NATURAL COAGULANT FOR COLOUR REMOVAL FROM RAW AND TREATEAD TEQUILA VINASSES (WITH CONSTRUCTED WETLANDS)

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Keywords: *Moringa oleifera* seeds; Horizontal Subsurface Flow Wetland; Vertical Upflow Wetland; Vertical Down Flow Wetland; pH; Coagulant Doses

ABSTRACT

Tequila is an alcoholic beverage produced in Mexico and during its production there is generation of a liquid waste namely vinasse. Tequila vinasse is characterized by a dark brown colour along (melanoidins produced during the feedstock cooking) with a high content of organic matter measured as chemical oxygen demand or biochemical oxygen demand, nutrients, total solids and an acidic pH (Zurita et al., 2022).

In this study, the aim was to evaluate a natural coagulant obtained from seeds of *Moringa oleifera (MOC)* to reduce the colour concentration in raw and treated tequila vinasse. The treated vinasses were the effluents of three types of pilot-scale constructed wetlands. The effluent of horizontal subsurface flow wetlands (HSSFW) was identified as TV-A; the effluent of vertical up flow wetlands (VUFW) as TV-B and the effluent of vertical down flow constructed wetlands (VDFW) as TV-C. The raw tequila vinasse (TV-D) was only subject to a sedimentation process. The full description of the HSSFWs and VUFWs are in Montoya et al. (2023) and the description of the VDFWs are in Zurita et al., 2023.

To obtain the *M. oleifera* coagulant, shelled seeds were crushed with a porcelain mortar and dried at 55 ^oC in an oven; then they underwent an oil extraction process with a Soxhlet extractor (Glas Col), crushed again and sieved to 500 um. The experiments to find the optimal pH value and coagulant dose were carried out in a Jarr Test equipment (Thomas Scientific) with three 1 L beakers. The rapid mixing was kept at 200 RPM for 3 min and was followed by slow mixing at 30 RPM for 30 min. The duration of sedimentation was kept constant at 45 min. When the optimum values were found, the test were performed in triplicate. In these tests, apparent colour, turbidity, pH, chemical oxygen demand and total suspended solids (TSS) were determined along with true colour (TrC) in initial and final samples of vinasses. All the parameters were determined according to standard methods for the analysis of water and wastewater (APHA, 2017).

For TV-A and TV-B, the optimum values for the coagulation-flocculation process was a doses of 1 g/L of MOC at a pH of 8. With these conditions, the TrC was reduced from 2520 Pt-Co units and from 2440 Pt-Co units to 1203.3 ± 49.3 and to 1180 ± 55.7 (Fig. 1), respectively with removals of TrC of 50.9% and 48.7%, respectively; meanwhile the TSS were removed in 73.62 % y 67.97 %, respectively (Fig.1). %. These results are similar to the 64% reported by Prasad (2009) when using MOC to reduce the colour in diluted stillage at an optimum pH of 8.5. With respect to TV-C, the optimum pH was 5 and a doses of 2.5 mg/L of MOC and the initial values of TrC of 7300 Pt-Co units was reduced to 1960.0 ± 69.2 Pt-Co units with a removal efficiency of 73.2. Regarding the raw TV that was only subject to a sedimentation process, the TrC increased in a pH range of 1.5 to 10.7; this although the initial value was 6360 Pt-Co units which was similar to the value of colour in TV-C.

Figure 1. Reduction of colour in TV-A with *Moringa oleifera* seeds. a, b, and c, beakers with samples of coagulated tequila vinasse; d, initial tequila vinasse.

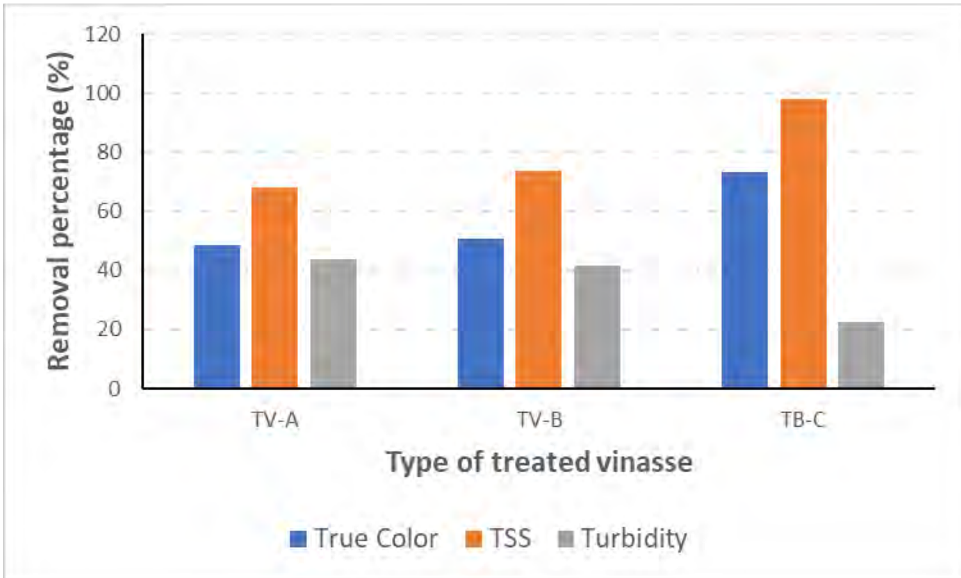

Figure 2. Removal of true colour, total suspended solids and turbidity from treated tequila vinasse (with constructed wetlands) by using a natural coagulant.

In this way, the natural coagulant from *M.oleifera* seeds significantly reduced the concentration of TrC in the three types of TV treated in constructed wetlands. However, the removal of TrC was not possible in the raw TV. These results suggests that the organic compounds responsible of colour in the tequila vinasse undergoes a transformation process when subjected to a biological treatment that allows it to coagulate-flocculate. Therefore, it can be concluded that it is feasible to use the coagulation-flocculation process with coagulant from *M. oleifera* seeds as a final stage of tequila vinasse treatment.

References:

APHA/AWWA/WEF, 2017. Standard Methods for the Examination of Water and Wastewater, 23th edn. American Public Health Association/ American Water Works Association/Water Environment Federation, Washington, DC, USA.

Montoya, A., Tejeda, A., Sulbarán-Rangel, B., Zurita, F. 2023. Treatment of tequila vinasse mixed with domestic wastewater in two types of constructed wetlands. Water Science and Technology. https://doi.org/10.2166/wst.2023.189

Prasad, R. K. (2009). Color removal from distillery spent wash through coagulation using Moringa oleifera seeds: Use of optimum response surface methodology. Journal of hazardous materials, 165(1-3), 804-811. https://doi.org/10.1016/j.jhazmat.2008.10.068

Zurita, F., Tejeda, A., Montoya, A., Carrillo, I., Sulbarán-Rangel, B., Carreón-Álvarez, A. 2022. Generation of tequila vinasses, characterization, current disposal practices and study cases of disposal methods. *Water*, *14*(9), 1395. https://doi.org/10.3390/w14091395

Zurita F., A Ramírez-Ramírez, A. A., Tejeda, Allan. 2023. Tratamiento de vinazas tequileras en humedales verticales de flujo descendente a escala piloto. Memorias del VI Conferencia Panamericana de Sistemas de Humedales para el Tratamiento y Mejoramiento de la calidad del Agua.

Treatment performance of constructed wetlands with subsurface horizontal flow after thirty years of operation

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Keywords: Constructed wetlands, removal efficiency, long-term performance, organics, nutrients

ABSTRACT

Constructed wetlands for treatment of municipal sewage have been introduced in the Czech Republic only in the early 1990s. The reason for this late introduction was lack of information on this type of wastewater treatment due to limited access to international scientific literature until 1990. The first available design guidelines were presented during the IWA conference on Wetland Systems in 1990 in Cambridge, United Kingdom (Cooper, 1990). Therefore, all constructed wetlands built in the early 1990s followed these guidelines, i.e. all systems were designed with horizontal subsurface flow, the vegetation was *Phragmites australis* and the surface area (A_h) was calculated according the formula: $A_h = Q_d$ (ln C_o – Ln C)/K_{BOD} , where Q_d is average flow (m^3 d^{-1}), Co and C are inflow and outflow BOD_5 concentrations, respectively (mg l^{-1}), and K_{BOD} is a rate constant (m d^{-1}) with a value of 0.1. The oldest systems, Ondřejov and Chmelná , put in operation in 1991 and 1992, respectively, are still in operation without any changes or refurbishments. The objective of this study is to evaluate long-term treatment performance of these systems.

CW Ondřejov is the first constructed wetlands for wastewater treatment built in the Czech Republic in 1991. The system was built to upgrade existing Imhoff tank which was the main treatment step before a constructed wetland was included in the treatment system. The CW was designed to treat sewage from the Astronomical Institution of the Czech Academy of Sciences which was located on the top of the hill above the village Ondřejov. **CW Chmelná** was built in 1992 and it was designed to treat municipal sewage together with stormwater runoff and drainage waters from a village. Both systems´pretreatment consists of screens, sand trap and Imhoff tank. Other parameters of both constructed wetlands are shown in Table 1.

Table 1. Basic parameters of CWs Ondřejov and Chmelná.

	Ondřejov	Chmelná
Designed PE	362	150
Number of connected people in 2021	226	147
Sewerage	separate	combined
Surface area (m^2)	806	706
Number of beds	1	2 (parallel)
Filtration material (fraction, mm)	crushed rock (5-10)	gravel (8-16)
Filtration bed depth	1.1	0.7
Average flow for the whole period (m^3 d^{-1})	56	55.6
OLR- measured for the whole period (kg BOD_5 ha^{-1} d^{-1})	181.5	66.9
HLR - measured for the whole period (cm d^{-1})	7.0	7.9

In Table 2, average inflow and outflow concentrations of BOD_5, COD, TSS, N-NH_4^+ and TP together with treatment efficiencies along the whole period of operation, are shown. The results clearly reveal that inflow concentrations at Ondřejow are much higher than at Chmelná, as the sewer system is separate and wastewater is not diluted by stormwaters or any other water. The inflow concentrations at Chmelná represent typical values from combined sewer systems in the Czech Republic. However, at both localities, the inflow concentrations vary widely. On the other hand, the outflow concentrations vary much less and are below the discharge limits set by Water Authorities. At CW Ondřejov the limits are set at 30 mg l^{-1} for

BOD_5, 90 mg l^{-1} for COD and 25 mg l^{-1} for TSS and the limit was exceeded only for BOD_5 during the second year of operation (Fig 1). At CW Chmelná, the limits are set at 19 mg l^{-1} for BOD_5, 80 mg l^{-1} for COD and 19 mg l^{-1} for TSS. These limits have always been met during the period 1992-2021 (Fig. 2).

Table 2. Average treatment efficiency of constructed wetlands Ondřejov and Chmelná during the periods 1991-2021 and 1992-2021, respectively.

	Ondřejov			Chmelná		
	Inflow (mg/l)	Outflow (mg/l)	Eff. (%)	Inflow (mg/l)	Outflow (mg/l)	Eff. (%)
BOD_5	272 (83-571)	13.9 (2.6-38)	93.4	82 (9-164)	5.6 (1.5-11.5)	91.3
COD	707 (188-2254)	50.3 (26-88)	90.2	174 (40-303)	33.9 (15.7-62)	81.7
TSS	434 (44-2389)	7.3 (2-22.8)	95.9	59.7 (20-129)	5.9 (1.0-13.2)	88.5
$N\text{-}NH_4^+$	39.4 (17-83)	21.6 (2.5-48.3)	41.4	15.6 (3.7-39)	9.0 (1.5-21.8)	39.3
TP	9.4 (3.5-34)	4.8 (1.3-21.1)	43.7	4.5 (0.7-9.4)	2.6 (0.4-7.5)	40.1

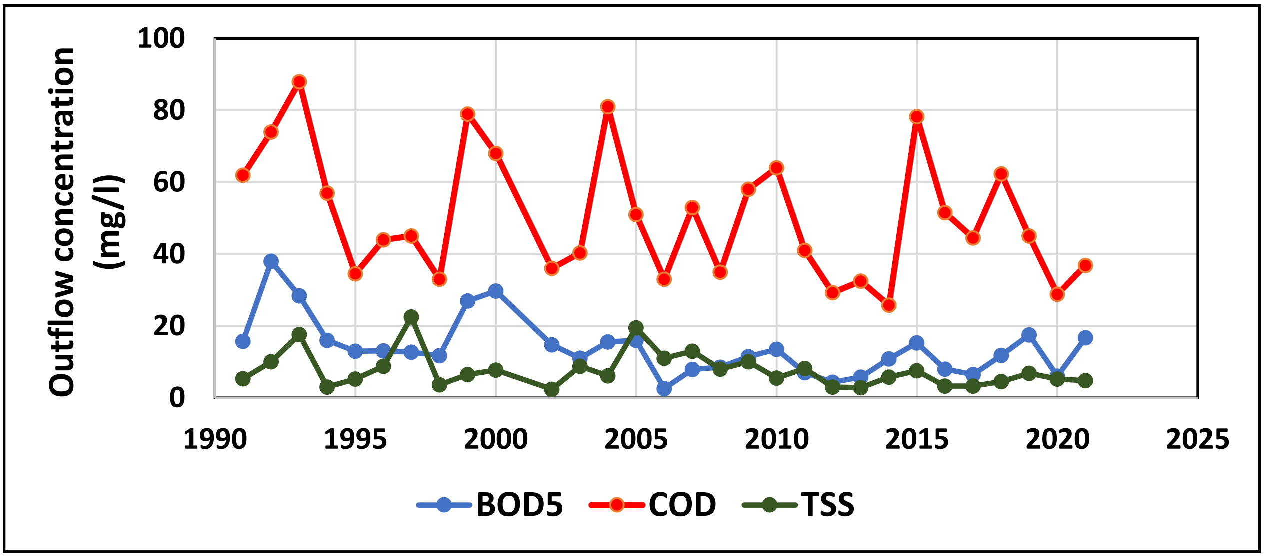

Figure 1. Average outflow concentrations at CW Ondřejov during the period 1991-2021.

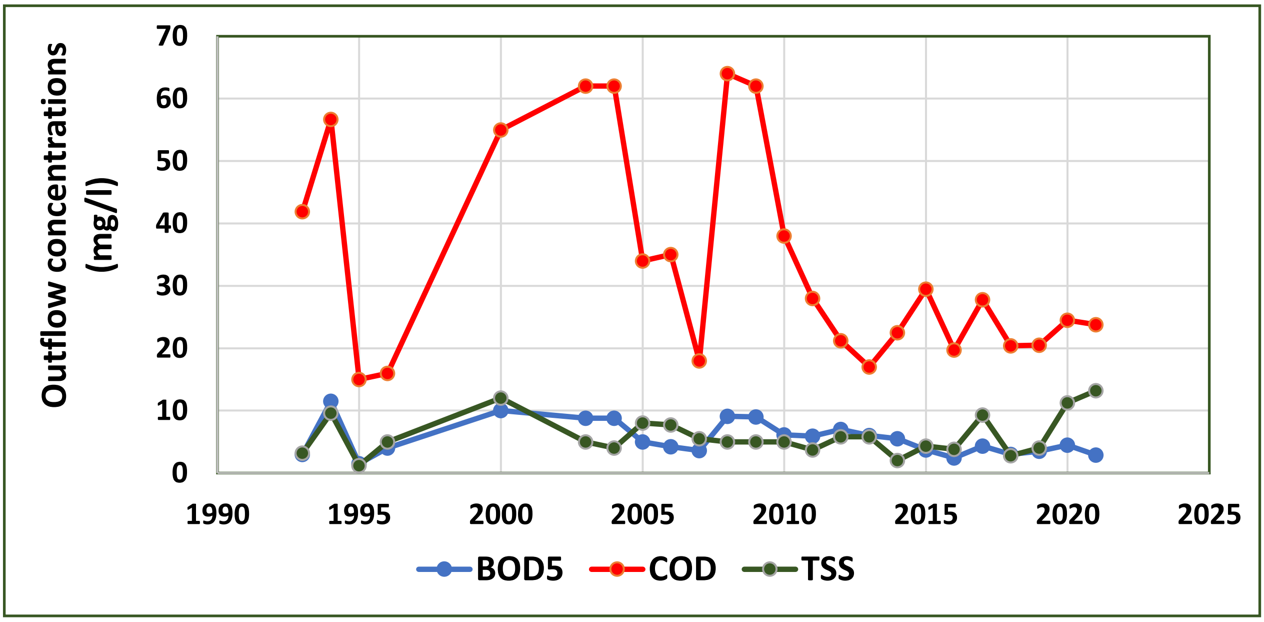

Figure 2. Average outflow concentrations at CW Chmelná during the period 1993-2021.

Both constructed wetlands have been operated for thirty years without any refurbishment despite a slight ponding at the inflow zone at CW Chmelná. However, it has been shown (Vymazal, 2018, 2019) that slight ponding does not affect the treatment performance. The results of this study indicate that the original design formula (Cooper, 1990) can successfully be applied for the design of the constructed wetlands with horizontal sub-surface flow. During the period of 1991-1998 as much as 63 CWs with horizontal sub-surface flow were built in the Czech Republic. At the moment, 48 systems are still in operation, i.e., they have been in operation for at least 25 years. The major reason why the CWs were terminated was a steep increase in population living in particular municipalities and inability to enlarge the current constructed wetlands for various reasons.

Constructed wetlands with horizontal sub-surface flow are not designed to remove ammonia or phosphorus due to prevalent anoxic conditions in the filtration beds (limited nitrification) and the use of filtration materials with low sorption capacity for phosphorus (gravel, crushed rock). The removal of ammonia and phosphorus usually amounts to about 40% (Table 2). However, in the Czech Republic the discharge limits for treatment plants <500 PE are set only for organics (BOD^5, COD) and suspended solids. Despite these limits, the current constructed wetlands in the Czech Republic are usually designed as either two-stage vertical-flow or hybrid constructed wetlands in order to achieve higher removal of nitrogen.

The present study revealed that treatment performance of constructed wetlands with horizontal sub-surface flow can be steady and sustainable for thirty years without and improvement or refurbishment of the system.

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References:

Cooper, P.F. (ed.), 1990. European Design and Operation Guidelines for Reed Bed Treatment Systems. Prepared by EC/EWPCA Emergent Hydrophyte Treatment Systems Expert Contact Group. Water Research Centre Report No. UI 17. Swindon, UK.

Vymazal, J., Does Clogging Affect Long-term Removal of Organics and Suspended Solids in Grave-Based Horizontal Subsurface Flow Constructed Wetlands? Chemical Engineering Journal 331, 663-674, http://dx.doi.org/10.1016/j.cej.2017.09.048

Vymazal, J., 2019. Is Removal of Organics and Suspended Solids in Horizontal Sub-Surface Flow Constructed Wetlands Sustainable for Twenty and More Years? Chemical Engineering Journal,378, 122117, https://doi.org/10.1016/j.cej.2019.122117

Septage treatment using the First Stage of French Vertical Flow Constructed Wetlands: From the commissioning to the closure of the system

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ABSTRACT

In developing countries, including Ecuador, a significant portion of urban population (15%) depend on on-site technologies like septic tanks for wastewater treatment due to the absence of sewage collection systems (Sturzenegger et al., 2020). Without further control, this often results in the discharge of untreated septage, causing significant environmental impacts.

The First Stage of French Vertical Flow Constructed Wetlands (FS-FVFCWs) represents a sustainable alternative for septage treatment. These wetlands are primarily designed for treating raw wastewater with the consequence of a deposit sludge layer formation on the top of the bed, which would resemble the organic deposit or sand layer of sludge drying reed beds (SDRBs). The wetland system allows the sludge layer reduction by dewatering and mineralization over the long term (Kim et al., 2018). This performance is influenced, in turn, by factors such as the type of plants, bed maturity, climatic factors, sludge characteristics, Hydraulic Loading Rate (HLR), Solids Loading Rate (SLR) and the loading frequency (Strande et al., 2014). Once the system has accomplished its useful life span, it is important to evaluate the contamination potential of the wetlands and the evolution of the sludge layer. Therefore, studying the whole cycle, from commissioning to closure, with different operational schemes is essential to completely understand the behaviour of the system.

This work presents the initial overview of the results in the performance of a pilot-scale Modified FS-FVFCW installed in Northern Tropical Andes, specifically in Cuenca, Ecuador (2°52´15.1´´S, 78°56´30.8´´ W) throughout the commissioning to the closure stages under three operational scenarios. The first scenario involved planting the FS-VFCW and loading septage with the outlet valve open, allowing the drainage of the leachate. The second scenario was set up with the FS-FVFCW planted and the leachate retained in the bed by closing the outlet valve to prevent drainage. The third scenario was similar to the second, but the FS-FVFCW remained unplanted. During the operational period, samples were collected from the septage at the inlet and the leachate at the outlet. Those samples were analysed for COD, BOD_5, TS and VS. Furthermore, samples were taken from the sludge deposit layer immediately after loading the pilot with septage, 24 hours after the loading and just before the next loading event. Sludge deposit samples were analysed for TS and VS and water content. After the operation period, the wetland was rested for a few months and then some samples of clean water percolating through the media (simulating a rain event) and the deposit sludge layer, were analysed for organic matter, nutrients and indicators of faecal contamination. The complete results from this study will be displayed in a full paper.

The commissioning period started in September 2020 and finished in January 2021. The wetland was initially loaded with raw wastewater to facilitate the establishment of the *Lolium perenne* vegetation in the unit, and then for the development of biomass inside the filter. The HLR applied was 0.94 m/d, with 24 batches a day with a volume of 0.382 m^3 for 2.5 min resulting in an instantaneous HLR of 0.93 m/h. During this period, the planted vegetation rapidly adapted to the climatic conditions of the zone and the wastewater characteristics demonstrating robust resistance for extended resting periods. This resilience

was particularly important because the wetland required a minimum resting period of 7 days for effective septage treatment.

During the operational period, different COD, BOD_5, TS and VS concentrations were found in the septage loaded on to the wetland. As depicted in Figure 1, the influent septage exhibited a considerable range of variation, with a peak during the sampling period. Septage variability can be attributed to its different sources, including septic tanks with different usage patterns, retention times, emptying practices, treatment performances, construction qualities and groundwater characteristics. The observed variability agrees with the common variations in faecal sludge characteristics (Andriessen et al., 2019), but is slightly more concentrated than the septage reported in the literature (Gan et al., 2018; Jain et al., 2022). However, for the effluent (leachate from the wetland) the variability was significantly reduced, including the peaks of concentrations. This demonstrates the robustness and effectiveness of the FS-VFCW to cope with realistic operation conditions.

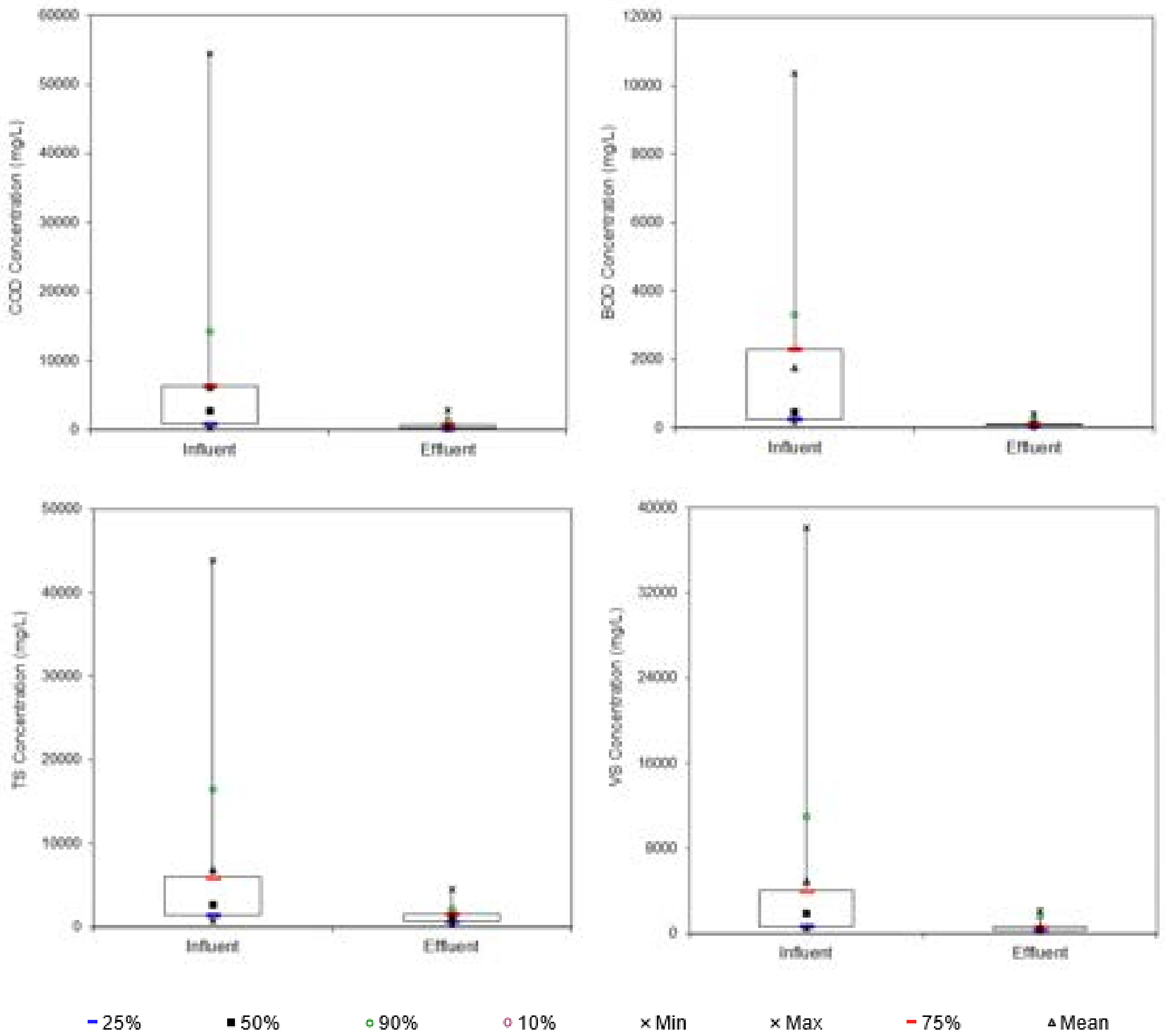

Figure 1. COD, BOD, TS and VS concentrations in the influent and effluent of the pilot

Mean removal efficiencies of 72.1 % (25.3%) for COD, 73.6 % (23.5%) for BOD_5, 57.3% (29.5 %) for TS and 63.18 % (27.9%) for VS were observed during the whole operation period. These values were found to be satisfactory. COD removal was within the common range of efficiencies obtained in SDRBs although TS removal was lower (Kim et al., 2018; Sonko et al., 2014). The main difference between FS-FVFCW and SDRB is the top filtration layer, which consists of sand in SDRB and the deposit sludge layer in FS-FVFCW. The deposit sludge layer is formed during the operation of the wetland, meaning that during the first operation months the top filtration layer of the pilot comprised a 30 cm of gravel with particle size between ϕ2 – 10 mm, which influenced the filtration potential of the treatment.

Analysing the performance of the pilot for the three scenarios, the results obtained indicated that the highest efficiencies of COD and TS removal were observed during the second scenario (Table 1). There was a decrease in both HLR and SLR applied from scenario 1 to 3. The HLR applied to the bed was lower because when the outlet valve was closed (scenario 2 and 3), the wetland could only receive septage up to its free volume capacity. The value of the SLRs depended on the HLR applied and the TS concentration in the influent, and as it could be seen in Figure 1, TS concentration was variable.

Table 1. Operation and performance conditions during the three scenarios

Scenario	COD removal (%)		TS removal (%)		HLR (m^3 m^{-2} $week^{-1}$)		SLR (TS kg m^{-2} y^{-1})	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	49.6 %	21 %	39.1 %	28.6 %	0.26	0.08	65.9	137.52
2	90.8 %	9.6 %	76.6 %	13 %	0.11	0.04	35	30.2
3	88.1 %	9.9 %	60.9 %	31.6 %	0.06	0.003	16	23.5

Using the Kruskal-Wallis test followed by Bonferroni-Dunn test, the three operational scenarios were compared, obtaining the results showed in Table 2. Regarding COD removal, a significant difference was observed between scenario 1 and the other two scenarios. The modification in scenarios 2 and 3 was the establishment of anaerobic conditions within the filter with the higher hydraulic retention time, resulting in a significant improvement of the COD removal efficiency (Table 1). For TS removal we found a difference only between scenario 1 and 2 while no significant difference was observed between 1 - 3 and 2 – 3. Considering that the leading mechanism for TS removal is filtration, the results obtained suggest that the absence/small height of the deposit layer during the first months of operation is the main factor affecting the TS removal performance, rather than the hydraulic retention time. Furthermore, the results showed that the role of the plants applied here (*Lolium perenne)* is not significant for COD and TS removal. However, macrophytes are indeed important for other processes occurring in wetlands (Bassan et al., 2014).

Applying the Kruskal-Wallis followed by Bonferroni-Dunn test we found that the reduction of HLR in scenario 3 compared to 2 (Table 1) was not solely because of the plants that were occupying the whole pilot, as there was no significant difference between 2-3 for HLR or SLR. The capacity of the pilot to accept a certain volume could have decreased as a part of the system clogging, showing that the rest time after each loading was insufficient for the wetland to recover.

Table 2. Comparison of the three operational scenarios

Scenario	COD removal (%)	TS removal (%)	HLR (m^3 m^{-2} $week^{-1}$)	SLR (TS kg m^{-2} y^{-1})
1 – 2	< 0.001***	0.013*	0.031*	0.71
1 – 3	0.003**	0.32	< 0.001***	0.043*
2 – 3	0.61	0.74	0.19	0.11

*,**,*** represent significant levels

The characteristics of the sludge layer after 4 months is presented in Table 3. The predominant material in the sludge layer was not organic material, as it accounted for 31.55% (13.71%). Comparing the values of the table with those reported for soil, N corresponds to a rich soil (>0.3%), while P corresponds to a low level (<12%) for soil fertility (Villasanti et al., 2013).

The concentrations of Total Coliforms and E. Coli showed that even after 4 months the sludge layer is not safe for agricultural purposes.

Table 3. Composition of the sludge deposit layer

Parameters	Mean
Phosphorous (%)	10.02
Nitrogen(%)	1.94
Carbon(%)	16.71
Organic Matter(%)	31.55
Total Coliforms(CFU/gr)	3000
E. Coli (CFU/gr)	4.5 E+06

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References:

Andriessen, N., Englund, M., Gold, M., Klinger, M., Luthi, C., Renggli, S., Sam, S., Strande, L., & Ward, B. 2019. *Faecal Sludge Management: Highights and Exercises*.

Bassan, M., Brdjanovic, D., Dangol, B., Dodane, P.-H., Hooijmans, C. M., Lopez-Vazquez, C. M., Mbéguéré, M., Mikhael, G., Diaz-Aguado, B. M., Niwagaba, C. B., Kenge, I. M., Ramsay, J. E., Reymond, P., Robbins, D. M., Ronteltap, M., Strande, L., & Tilley, E. 2014. *Faecal Sludge Management* (L. Strande, M. Ronteltap, & D. Brdjanovic (eds.)). IWA Publishing. https://www.un-ihe.org/sites/default/files/fsm_book_lr.pdf

Gan, C., Champagne, P., & Hall, G. 2018. Pilot-scale evaluation of semi-passive treatment technologies for the treatment of septage under temperate climate conditions. *Journal of Environmental Management*, *216*, 357–371. https://doi.org/10.1016/j.jenvman.2017.05.079

Jain, M., Upadhyay, M., Gupta, A. K., & Ghosal, P. S. 2022. A review on the treatment of septage and faecal sludge management: A special emphasis on constructed wetlands. *Journal of Environmental Management*, *315*(April), 115143. https://doi.org/10.1016/j.jenvman.2022.115143

Kim, B., Bel, T., Bourdoncle, P., Dimare, J., Troesch, S., & Molle, P. 2018. Septage unit treatment by sludge treatment reed beds for easy management and reuse: Performance and design considerations. *Water Science and Technology*, *77*(2), 279–285. https://doi.org/10.2166/wst.2017.461

Sonko, E. hadji M., Mbéguéré, M., Diop, C., Niang, S., & Strande, L. 2014. Effect of hydraulic loading frequency on performance of planted drying beds for the treatment of faecal sludge. *Journal of Water, Sanitation and Hygiene for Development*, *4*(4), 633. https://doi.org/10.2166/washdev.2014.024

Strande, L., Ronteltap, M., & Brdjanovic, D. 2014. Faecal Sludge Management. In *Faecal Sludge Management*. https://doi.org/10.2166/9781780404738

Sturzenegger, G., Vidal, C., Martinez, S., & Yarygina, A. 2020. *The Last Mile Challenge of Sewage Services in Latin America and the Caribbean* (Issue November).

Villasanti, C., Román, P., & Pantoja, A. 2013. El manejo del suelo en la producción de hortalizas con buenas prácticas agrícolas. In *Food and Agriculture Organization of the United Nations*.

Large-scale constructed wetlands from Brazil to the Middle East: scaling up NBS

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Keywords: constructed wetlands, aerated wetland, substrate media, wastewater treatment

ABSTRACT

Wetland systems are able to transform and/or remove various pollutants (organics, nutrients, trace elements, etc.) through a series of physical, biological, and chemical processes, and therefore improve water quality. The wide range of economic and ecological benefits of wetlands stimulated the interest to exploit their natural water purification capacity for different applications, particularly for wastewater treatment. Human-made wetland ecosystems exploit these purifying functions of natural wetlands, which have been used for the disposal and treatment of secondary and tertiary wastewater effluents for many years in the past. Nowadays, natural wetlands are rarely used for the polishing of light-contaminated effluents in some areas, but generally their use for wastewater treatment purposes is mostly avoided around the world, since this could cause irreversible damage to ecosystems. The basic concept of CW systems is to replicate the various naturally occurring processes under controlled conditions for a beneficial purpose, e.g., treatment of wastewater. This means that CWs are designed in such a way as to mimic and enhance the functions of natural wetlands. Although CWs offer in general the same values and functions with natural wetlands, they provide a wider range of ecosystem services; it has been shown that CWs possess a higher value in terms of flood and stormwater control, water quality improvement and biodiversity restoration. Their main design characteristics make them more easily adopted and integrated into the built environment by urban planners, engineers, and landscape architects. CWs represent a very interesting and effective development in the field of ecological engineering.

This study will present different examples and case studies of CW from around the world, but focusing on large-scale CW systems. The goal is to demonstrate that CW can be designed and built as big as possible, considering however the space limitations that typically limit the application range and scalability. Large land area requirement is a major limitation of its application especially in densely populated and mountainous areas. Nevertheless, there are already many large such systems that demonstrate the upscaling possibilities of CW technology. This study will present CW facilities from:

<u>Saudi Arabia 1</u>

- 16.000 m^3/day,
- Estimated population > 70,000 people
- Largest CW project in the world for municipal wastewater
- 13.5 hectares of treatment wetlands
- 1.5 million reed plants (Phragmites, Typha, Arundo and Cyperus)
- treated sewage effluent reused for irrigation in landscaping

<u>Saudi Arabia 2</u>

- 100.000 m^3/day
- Receiving effluent from an industrial WWTP and a municipal WWTP, not meeting discharge criteria
- 200 hectares for Constructed Wetland
- 100 ha storage pond

<u>Mexico</u>

- 8640 m^3/day
- Effluent from the Cerro de la Estrella Wastewater Treatment Plant (Cerro WWTP)
- Goal is to meet the Mexico Water Quality Limits for Human Consumption (NOM-127-SSA1-2017) and produce effluent quality that can be reused as a potable supply for Mexico City

<u>Brazil</u>

- polymetallic mine and concentrate processing facility: proven reserves of Zn, Pb, Cu, Ag, Au
- 21.64 m^3/sec
- 5 wetland systems
- Treating water from the ore beneficiation process (Fe, Cu, talc, Zn), the mine drainage (Al, F, Pb, Pb and Mn), stormwater / waste heap runoff and waste tailings

<u>Oman</u>

- Produced water treatment from oil exploration and separation
- 175.000 m^3/day
- Constructed wetlands: 490 hectares (4.9 million m^2)
- Evaporation ponds & salt-works: 780 hectares (7.8 million m^2)

Session C5: Bio-based materials II

Optimization of biochar filter for handwashing wastewater treatment and recycling at the point of use

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Keywords: biochar filter, circular economy, handwashing, sustainability, water recycling

ABSTRACT

INTRODUCTION

Handwashing wastewater (HW) from portable stations without piped drainage systems is commonly discarded into the ground damaging the environment and public health. Therefore, it is critical to develop a sustainable handwashing station with an on-site wastewater treatment technology for water recirculation. Current HW recycling technologies rely on expensive, high-energy demanding, and high-maintenance technologies (e.g., membrane filtration, reverse osmosis) which limit their replicability in low-income countries. Due to its excellent physicochemical properties, biochar, a material formed from the thermal decomposition of organic waste, is proven to remove a wide range of greywater pollutants. Yet, the use of biochar filtration and the optimization of its operation conditions for HW treatment and recycling is still unknown. To address this knowledge gap, this study used Response Surface Methodology (RSM) to optimize operating conditions such as particle size, filter depth, and flow rate to remove colour, turbidity, phosphates, and *E. coli* from HW. This is relevant to predicting pollutant removal efficiencies based on operation parameters for the integration of biochar filtration along with portable handwashing facilities to treat and recycle wastewater on-site in environments with limited water services and quality.

MATERIALS AND METHODS

Optimization of the biochar filter configurations. Box-Behnken design (BBD) from RSM evaluated the combined effect of operation parameters: particle size, filter depth, and flow rate (independent variables) on colour, turbidity, phosphates, and *E. coli* removal (dependent variables) from HW (Table 1). The BBD design used three operational parameters with three levels each and three centre points. The three operational parameters were: (i) particle size, (ii) filter depth, and (iii) flow rate. The three levels for each parameter were low (referred to as -1), medium (referred to as 0) and high (referred to as +1) levels. Particle size varied from 0.5 - 2.0 mm, filter depth was in the range of 15 - 30 cm, and the flow rate ranged from 1.0 - 2.5 L/h.

Table 1. Experimental range of operational parameters used in the BBD design.

IV	Parameter	Units	Low value (-1)	Medium value (0)	High value (+1)
A	**Particle size**	**mm**	**0.5**	**1.25**	**2.0**
B	**Filter depth**	**cm**	**15**	**22.5**	**30**
C	**Flow rate**	**L/h**	**1.0**	**1.75**	**2.5**

IV: Independent variables

Experimental set-up and operation of biochar filters. Fifteen downward biochar filters configurations were constructed in this study to evaluate their performance to remove the selected pollutants (Table 2). The bottom part of all filters was packed with 2.5 cm of gravel, 2.0 cm of glass wool, and 4.0 cm of silica sand. Based on the configuration, in the medium part, the biochar layer had a depth of 15, 22.5, and 30 cm; and particle size of 0.5, 1.25, and 2.0 mm. The top part had 2.5 cm of gravel. A stainless steel wire mesh of 4.5 cm diameter between layers acted as a layer separator and prevented small particle-size media from washing away. B**iochar filters were fed** under non-saturated conditions **with 2.5 L of** synthetic HW at a flow rate of 1.0, 1.75, and 2.5 L/h three times per week for 5 weeks. The synthetic HW was composed of sodium dodecyl sulphate, kaolin clay, cellulose, glycerol, lactic acid, sodium hydrogen carbonate, sodium chloride, and *E. coli* DH5α. Raw HW and effluent samples from the biochar filters were analysed for colour, turbidity, phosphates, and *E. coli* using standard methods for wastewater analysis.

Table 2. Biochar filtration configurations with varying operating conditions.

	Configuration														
IV	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
A	1.25	1.25	0.5	2	0.5	1.25	1.25	2	1.25	0.5	1.25	1.25	2	2	0.5
B	30	15	22.5	22.5	22.5	15	30	22.5	22.5	30	22.5	22.5	30	15	15
C	2.5	2.5	2.5	2.5	1	1	1	1	1.75	1.75	1.75	1.75	1.75	1.75	1.75

IV: Independent variables. A: particle size (mm), B: filter depth (cm), C: flow rate (L/h)

Model development, filter optimization, model validation, and further performance analysis. Based on experimental data, model equations representing the relationship between independent and dependent variables were obtained using Design-Expert Software (DES). Statistical (Analysis of Variance ANOVA) and practical (standard deviation, coefficient of variation, R^2, adjusted R^2, predicted R^2, and adequate precision) tests were used to evaluate the goodness of fit of data to regression models. Optimal conditions (particle size, filter depth, and flow rate) and their corresponding pollutants removal predictions were software-proposed. Models were validated by evaluating the performance of biochar filtration in triplicate under optimum conditions. The optimized biochar filter was also evaluated for the removal of COD, TSS, nitrates, ammonium, hardness, sulphates, and chloride. The purpose of this was to provide insights into the potential of the optimized biochar filter to remove a wide range of water pollutants to levels in compliance with international water quality guidelines for drinking water and water reuse applications.

RESULTS AND DISCUSSION

Model development. Using experimental data on pollutant removal from the fifteen-biochar filtration configurations, four quadratic models were developed to explain colour, turbidity, phosphates, and *E. coli* removal under varying operation conditions (Table 3). The statistical significance test (ANOVA) suggested that the proposed models were significant (p-value < 0.05) to explain the relationship between the independent and dependent variables. Practical significance tests demonstrated the models were accurate (little standard deviation), reproducible (coefficient of variation lower than 10%), and useful (adequate precision ratio greater than 4) for making removal predictions (Table 4).

Table 3. Quadratic regression models proposed by the Design-Expert Software.

Responses	Regression Model
Colour % removal (Y_1)	$138.73 - 1.30A + 0.34B - 70.39C + 20.10C^2$
Turbidity % removal (Y_2)	$121.95 + 0.26B - 44.95C + 12.60C^2$
Phosphates % removal (Y_3)	$125.89 - 61.36C + 18.14C^2$
E. coli % removal (Y_4)	$- 67.77 - 10.17A + 3.22B + 148.98C - 0.05B^2 - 44.96C^2$

A: particle size (mm), B: filter depth (cm), C: flow rate (L/h)

Table 4. Statistic summary of model goodness of fit.

Statistic parameter	Colour removal (%)	Turbidity removal (%)	Phosphates removal (%)	*E. coli* removal (%)
ANOVA ($p < 0.05$)	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Standard Deviation	1.30	1.27	1.96	1.52
Coefficient of variation (%)	1.46	1.39	2.47	2.07
R^2	0.970	0.926	0.898	0.994
Adjusted R^2	0.957	0.906	0.882	0.991
Predicted R^2	0.923	0.851	0.860	0.983
Adequate Precision	23.22	17.82	13.44	54.31

ANOVA: Analysis of Variance, R^2: Coefficient of determination

Response surfaces: combined effect of operation conditions on pollutants removal. Colour and turbidity removal increased with longer filter depth and lower flow rate. Suspended matter agglomeration, precipitation, straining, and adsorption at longer depths and smaller particle sizes favoured removal. Effective colour and turbidity removal suggested biochar filtration could eliminate the soapy appearance of handwashing water improving its appearance for water recycling. Phosphate removal was mainly affected by flow rate and due to chemical precipitation between phosphate ions and Mg, Ca, Fe, or Al on the biochar surface. Biochar filtration holds the potential to provide dual benefits in removing phosphates nutrients from HW while simultaneously packing the biochar filter material with phosphates ions for further reuse in soil enhancement applications (biochar filter media should first be thermally treated to break down anionic surfactant compounds, which can damage soil properties and plant germination). *E. coli* removal increased with longer filter depth, smaller particle size, and a medium level of flow rate through microbial adsorption and surface biofilm straining processes (Fig. 1). Biochar filtration can be an alternative to conventional microbial disinfection methods (e.g., chlorination, UV, ozonation). However, long-term assessment is key to estimating the life span of the system and suggesting successive treatment steps if needed. Further chlorination as a secondary treatment can be explored after biochar filtration to ensure microbiologically clean water with the presence of 0.2 mg/L of free chlorine).

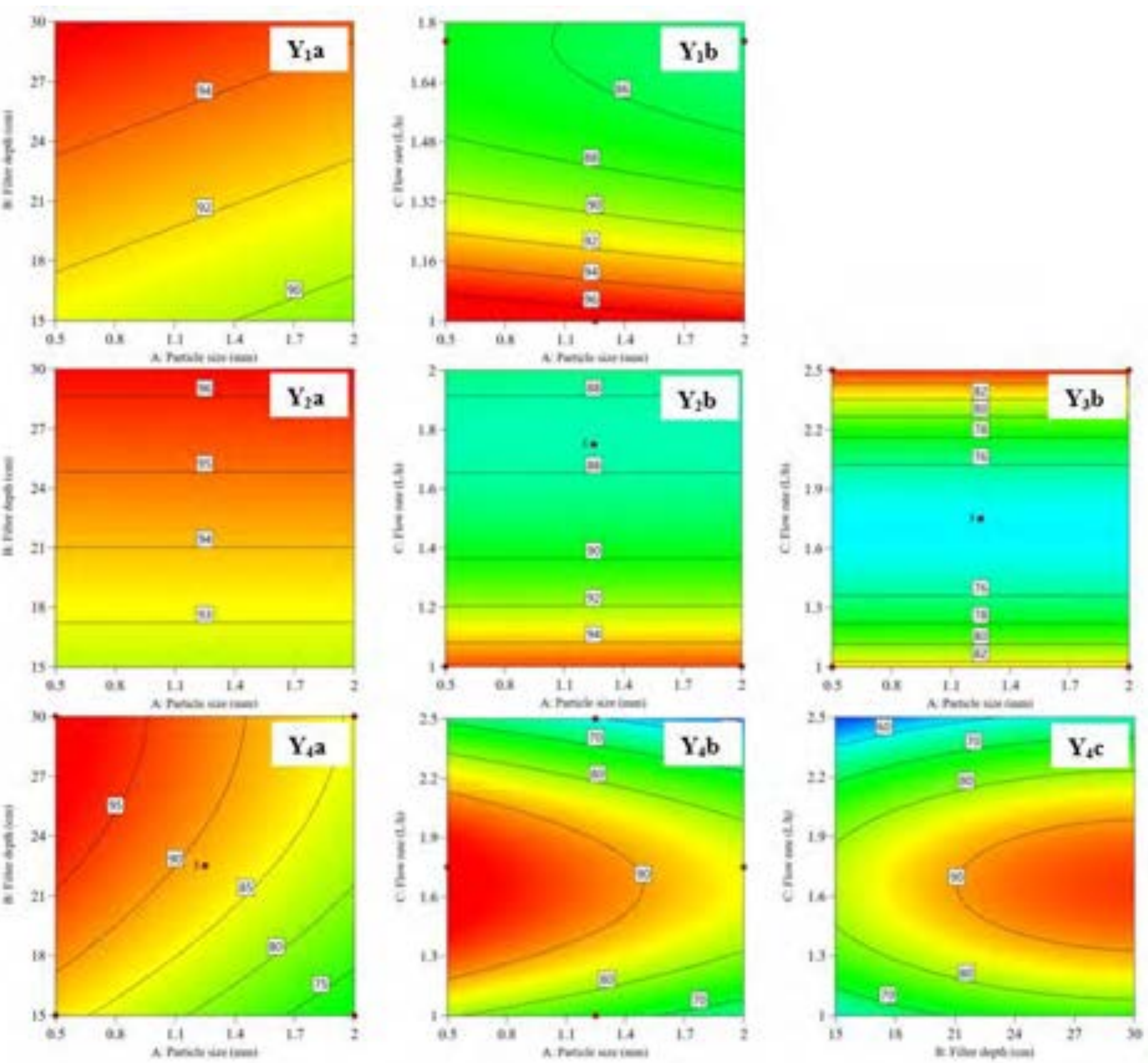

Figure 1. 2D contour plots of colour (Y_1), turbidity (Y_2), phosphates (Y_3), and *E. coli* (Y_4) removal. (a) Interaction of particle size and filter depth at a flow rate fixed at 1.06 L/h. (b) Interaction of particle size and flow rate at filter depth fixed at 30.0 cm. (c) Interaction of filter depth and flow rate at particle size fixed at 1.0 mm.

Process optimization and validation. Optimum conditions were 1.25 mm particle size, 30.0 cm filter depth, and 1.0 L/h flow rate, corresponding to predicted removals of 97.06, 97.50, 82.67, and 73.06% for colour, turbidity, phosphates, and *E. coli*, respectively. Experimental removal efficiency data of biochar filter operated at optimal conditions were 97.63, 99.85, 85.94, and 76.08% for colour, turbidity, phosphates, and *E. coli*, respectively. Removal values were within the range of 95% PI low and 95% PI high validating the predictive capability of the developed models (Table 5). Optimized biochar filtration can also achieve 56.3, 94.5, 6.1, 92.4, 61.3, 54.7, and 4.3% removal for COD, TSS, nitrates, ammonium, hardness, sulphates, and chloride, respectively, in agreement with some international drinking and water reuse regulations (e.g., WHO, EPA)

Table 5. Model validation experiments ($\alpha = 0.05$).

Analysis	Predicted Mean	Std. Dev.	N	95% PI low	Experimental Mean	95% PI high
Colour removal (%)	97.06	1.30	3	94.62	97.63	99.50
Turbidity removal (%)	97.50	1.27	3	95.15	97.93	99.85
Phosphates removal (%)	82.67	1.96	3	79.41	80.93	85.94
E. coli removal (%)	73.06	1.52	3	70.03	75.33	76.08

Std. Dev.: Standard Deviation, N: number of experimental runs, PI: prediction interval

CONCLUSION

Biochar filtration can be a low-cost alternative to HW wastewater treatment and recycling along with portable handwashing stations. However, when recycling treated HW for handwashing practices, it is recommended to avoid hand-to-mouth contact to prevent any infection risk, as the water quality does not entirely meet the extended quality criteria for drinking water purposes. This innovative decentralised strategy can help manage HW sustainably while providing clean water for poor settings lacking handwashing infrastructure, continued water service, and high-quality water sources. In addition, used biochar can be thermally treated for re-use as a soil improver, thus, biochar filtration can be a zero-waste water cleaning approach. However, to ensure the microbial safety of treated water, further studies exploring microbial disinfection as a secondary treatment after biochar filtration are highly recommended.

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References:

Almanassra, I.W., Mckay, G., Kochkodan, V., Atieh, M.A., Al-Ansari T. 2021. A state of the art review on phosphate removal from water by biochars. Chemical Engineering Journal 409, 128211, http://doi.org/10.1016/j.cej.2020.128211.

Bautista Quispe, J.I., Campos, L.C., Mašek, O., Bogush, A. 2022. Use of biochar-based column filtration systems for greywater treatment: A systematic literature review. Journal of Water Process Engineering 48, 102908, https://doi.org/10.1016/j.jwpe.2022.102908.

Enaime, G., Baçaoui, A., Yaacoubi, A., Lübken, M. 2020. Biochar for wastewater Treatment—Conversion technologies and applications. Applied Sciences 10 (10), 3492, https://doi.org/10.3390/app10103492.

Tiruneh, A.T., Ndlela, W.N., Heikkilä, J. 2016. Development of “Press Tap” Hand Washing Technology: Design, Construction and Operational Aspects. International Journal of Science, Technology and Society 4 (3), pp. 48-56, https://doi.org/10.11648/j.ijsts.20160403.12.

Removal of Heavy Metals and Antibiotics from Water Using Biochar: From Lab to Real-World Use

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ABSTRACT

Biochar is a long-lasting sorbent, low-cost and eco-friendly that can remove heavy metals from water such as Arsenic, Boron, and Bromate. Biochar can also be effective in removing antibiotics. Heavy metals and antibiotics are commonly found in treated wastewater. Their concentrations are usually small. Reuse of treated wastewater might be hampered due to their presence. As such treatment (or post-treatment) of wastewater using biochars needs comprehensive research. Below are findings from some recent laboratory scale studies done by the students of Sultan Qaboos University, Oman. Laboratory trials using biochars follow a standard path: biochar characterization, preparation of solutions containing various pollutants, the study of the removal of the pollutants under various conditions, analyze the data, fitting data to isotherms models, developing kinetic models and finding the optimum conditions with highest removal efficiencies. Such trials are mostly conducted by postgraduate students with a bias toward showing results that attain high removal efficiency. Absent from such studies are actual implementation of the findings in a real-world situation. The real-world situation is much different from the conditions in the laboratory. In most cases, the conditions in real life will make it almost impossible to construct a functional treatment system using biochar.

A research project (Al Haji, 2022) aimed to remove Arsenic and Bromate using date palm and mesquite biochar before and after Fe-enhancement through batch experiments. It was observed that Fe-enhanced date palm biochar had 16% higher removal efficiency of Arsenic than pristine biochar. While pristine mesquite biochar had 27% higher removal efficiency than enhanced mesquite biochar. For Bromate, pristine biochar had 67.6% higher removal efficiency than enhanced date palm biochar. While pristine mesquite performs much better than Fe-enhanced biochar at high Bromate concentration. The results showed that Fe-enhanced mesquite biochar has the ability to reduce As concentration up to 46.5% due to the great increase in the oxygen-containing functional group. In order to have a functional Arsenic removal system using enhanced date palm will require Fe-enhanced biochar (capable of 45% removal efficiency). The target value of Arsenic in Oman wastewater is 0.1 mg/L. This implies a series of tanks (reactors) will be needed with adequate contact time (24 hours in this study) and a biochar dose of 10 mg/L. Daily wastewater production in Muscat will soon reach 1 Mm3/day. As such, we will need a huge amount of biochar to be used as an adsorbent in granular form, a land area to operate these reactors, mixing facilities, a facility to enhance the biochar, and most importantly a facility to get rid of all the used biochar. It will be a formidable operation. The biochars were not investigated for regeneration and not studied for use in a filtration column like activated carbon.

Another study (Al Saidi, 2022) tested the efficiency of a low-cost and locally available agricultural waste of *Parthenium hysterophorus* weed (PW) in Boron (B) removal from aqueous solutions. In this study, PW was utilized as an unmodified powdered raw material, activated carbon (CPW), chemically treated PW and Ash-PW in an environmentally friendly manner to remove boron from B-contaminated aqueous media prepared synthetically. Different experimental parameters were tested for adsorption efficiencies such as initial solution pH; both adsorbent-PW size and dose; contact time; and temperature. The results showed that under the same conditions of using unmodified-PW, optimum boron removal was up to 98.4% at 15 ppm concentration followed by removal of 95.4% at 120-minutes contact time with adsorbent, 94.6 % at pH 6.0, 94.5% at 50°C temperature, and 94.1% at 0.1g biochar dose. Boron uptake using PW derived from shoot showed better boron removal compared to that sourced from stems and roots except for stem-CPW with a particle size of 0.500 µm. Among other treatments, PW impregnated with iron-(II) alone revealed the highest Boron elimination than aluminum and the combination of both. In this study removal percentage is much higher and the contact time is only 2 hrs with a biochar dose is 0.1 g/L. The study looked at increasing temperature to 50 C and lowering pH to 6 to increase removal efficiency which will

be problematic as operational conditions. For a wastewater plant of 12,000 m3/day, a 2-hr reactor volume will be 1,000 m3, and the total biochar requirement will be 1,200 kg. Fe-enhanced biochar will have to be prepared on-site as well as final disposal of the 1,200 kg of used biochar daily will have to be considered.
Antibiotics are potential environmental contaminants and their existence in the environment is increasing over the years. Globally, their residues have been found in terrestrial and aquatic systems. Long-term antibiotic persistence in the environment is likely to result in many health risk issues. Amoxicillin (AMX) is a kind of antibiotic and it was found in treated wastewater. Adsorptive removal of AMX was studied using corn husk-based biochar (CHBC) in a study (Al Subhi, 2022). Three main variables were studied; the pH. (4.0, 7.0, and 10.0), the initial concentrations of the adsorbates (10, 50, and 100 mg/L), and the dosage of the adsorbent, corn husk, (0.025, 0.05, and 0.075 g/mL). The enhanced biochar with FeCl3 was also studied. Additionally, any alterations in the surface area of the adsorbent were studied physically and chemically. The results showed the optimized pH for the adsorptive removal of amoxicillin using CHBC was 7.0. Conclusively, CHBC showed high efficiency in eliminating AMX. However, the maximum removal was 98.7%, which was achieved at 0.025 g/mL adsorbent dose and 50 mg/L AMX initial concentration. In this particular experiment biochar dose is extremely high, 25 g/L, 3 hr contact time and initial AMX concentration of 50 mg/L. First of all, the mixing reactor will have to be 1,500 m3 for a flow of 12,000 m3/day, and 300 tons of biochar will be required daily. But most unlikely is the concentration of AMX used (50 ppm) which is never likely to be encountered in real life and has been measured only in the ppb or parts per trillion range. Whether biochars will work when the AMX concentration is extremely low was not studied. In simple words, it will be almost impossible to implement the findings of this research in a real-world situation.
In another study (Al Busaidi, 2022), slow pyrolysis (600 °C) was used to develop a novel method for producing enhanced biochar from KMnO4-treated date palm fiber. In comparison to pristine biochar, the enhanced biochar (EBC) had a larger surface area along with more surface oxygen-containing functional groups (BC). The pristine and enhanced biochar surface area, surface morphology, and surface functional groups, were evaluated using SEM-EDS, ICP-OES, BET analyzer, and FTIR. As (III) adsorption behavior was evaluated in terms of adsorption capacity (qe) and removal efficiency (E). Batch sorption experiments revealed the enhanced biochar had significantly higher sorption capacity and removal efficiency of As(III), with a maximum removal efficiency of 70% and 40% respectively for EBC and BC. Batch sorption experiments also revealed that solution pH (3, 7 and 9), adsorbate concentration (5, 50 and 100 ppm) and adsorbent dose (0.05, 0.2, and 0.4 g/0.025 L), all influenced the biochar's ability to remove Arsenic from water. The data fit the Langmuir model (r2= 0.97) better than the Freundlich adsorption isotherm model. The biochar could be regenerated successfully using a 0.1 M NaOH aqueous solution. These laboratory findings will be difficult to implement in a real-world situation as the biochar dose is very high (16 kg/m3) and removal efficiency is relatively low. One positive aspect of this research was the regeneration of the used biochar, which was investigated and found possible.
Based on this small sample of laboratory experiments (four studies) using plant-based biochar to remove heavy metals and antibiotics from water, the following conclusions could be made: biochar does remove heavy metals and antibiotics but experimental conditions are not reflective of real-world situations. Usually, biochar doses are extremely high, the simulated pollutant concentrations are abnormally high, in some cases pH and temperature modification is necessary, and how a huge amount of used biochar will be handled is not discussed. The time has come for changing focus from lab-based removal trials to actually implementing findings in real-world conditions.

References

Zainab Hamed Al Haji. 2022. Arsenic and Bromate removal from water using date palm and mesquite biochar. Unpublished MSc research project report, Sultan Qaboos University, Oman.

Shaima Al Saidi. 2022. An Investigation of Using A Local Invasive Weed (*Parthenium hysterophorus*) For Removing Boron From Aqueous Solutions. Unpublished research project report, Sultan Qaboos University, Oman.

Afrah Al Subhi, 2022. Corn Husk-based Biochar and its role in Amoxicillin removal. Unpublished research project report, Sultan Qaboos University, Oman.

Aisha Al Busaidi, 2022. Removal of Arsenic from Aqueous Solutions using Natural Biochar-Based Sorbent from Fibers of Date Palm (*Phoenix dactylifera*). Unpublished research project report, Sultan Qaboos University, Oman.

Production and characterization of Carbon Nanotubes and Graphene Oxide biochar nanocomposites from rice husks and sewage sludge and adsorption tests on six Emerging Contaminants from wastewater

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Introduction

Biomass reuse is one of the main subjects towards sustainability and zero-waste policy [Ma et al., 2022]. Biochar is the solid product of biomass pyrolysis that presents several favorable physicochemical properties, making it a good candidate for several applications, such as soil amendment, adsorptive material, constructed wetland substrate, compost enhancer and other smaller-scale applications [Oni et al., 2022]. Such properties are its good porosity and C content, large surface area, abundance of surface functional groups and high remediation potential [Qambrani et al., 2017]. The environmental application of biochar as an adsorptive material has gained a lot of attention during recent years, highlighting the sustainability aspect concerning the reuse of waste in order to produce new materials that are going to be further applied for anti-pollution purposes [Ayaz et al., 2021]. Activated Carbon (AC) is currently the main competitor of biochar, being produced in the same manner as biochar with an added activation step at the end of the process. Several techniques have been investigated in literature concerning the modification of biochar towards an advanced final material that is able to compete with AC and show better physicochemical properties. One of these techniques is the production of biochar nanocomposites, a technology that combines biochar and nanotechnology towards the production of advanced and highly efficient adsorptive materials [Amusat et al., 2021]. Emerging Contaminants (ECs) are organic pollutants found in low concentrations (ng L^{-1} to μg L^{-1}) in Wastewater Treatment Plant (WWTP) effluents and in surface waters and are being thoroughly investigated recently because of their potential harm to the aquatic environment and its habitats [Richardson & Kimura, 2019].

The goal of this study was to produce and characterize biochar and biochar nanocomposites from Rice Husks (RH) and Sewage Sludge (SS), representing an agronomic and environmental waste type accordingly, combined with two nanomaterials, Graphene Oxide (GO) and Carbon Nanotubes (CNTs), at 600°C, in order to apply them as adsorbents for the decontamination of secondary wastewater effluent from six ECs; 2,4-Dichlorophenol (2.4D), Bisphenol A (BPA), Norethindrone (NOR), Androsterone (ADT), Estradiol (E1), Ethinyl Estradiol (EE2).

Materials and methods

Two biomass types were used as feedstock for biochar nanocomposite production; Rice Husks (RH) received from a local rice mill in Northern Greece and secondary de-watered Sewage Sludge (SS) collected from Psytalleia WWTP in Attica, Greece. Two nanomaterials, GO and multi-walled, -COOH functionalized CNTs were implemented into raw biomass for the production of biochar nanocomposites. Biomass samples were initially oven-dried at 90°C for 48h and then pulverized to a particle diameter <0.5 mm. Nanomaterial implementation into the biomass was achieved by applying the dip-coating procedure aiming to a 10% w/w ratio of nanomaterial to biomass, as described in our previous work [Regkouzas et al., 2023]. Biochar nanocomposites were produced in a muffle furnace, at 600 °C for 1h, using a heat rate of 6 °C min^{-1} and a 200 L h^{-1} supply rate of 99% pure N gas.

Physicochemical characterization of the produced samples included organic C content (C_{org}), Specific Surface Area (S_{BET}), pH and ash content determination, while the adsorption experiments were performed on six ECs; 2.4D, BPA, NOR, ADT, E1 and EE2, which were spiked to 500mL of secondary wastewater, before the chlorination stage, collected from the Municipal Water & Sewerage Company of Chania (DEYAX). The following close-to-realistic initial concentrations were selected to produce the polluted mix: 2-4D and BPA: 20-40μg L^{-1}, E1 and EE2: 40-60μg L^{-1}, ADT and NOR: 70-90μg L^{-1}. The adsorption experiments took place in light-insulated conical flasks, at 22±1 °C. 50 mL of the aqueous polluted sample and 0.15g of biochar (equal to a dose of 3g L^{-1}) were added in the flasks and three residence times were investigated for each sample type, 10min, 30min and 60min concerning the GO nanocomposites, while 5min, 10min and 30min were selected for the CNT nanocomposites, due to higher adsorption efficiency. Pollutant analytical determination was achieved by Solid Phase Micro-Extraction (SPME) followed by GC-MS analysis, as described in our previous work [Regkouzas & Diamadopoulos, 2019].

Results and discussion

The results concerning the physicochemical characterization of biochar are presented in Table 1. CNT doped biochar nanocomposites showed better physicochemical properties, compared to GO biochar nanocomposites, while on the same time, RH feedstock also provided better results compared to SS. Specifically, RH biochar nanocomposites showed higher C_{ORG} content by 35.5-44.4% compared to SS nanocomposites, higher surface area by 73.9-79.8%, lower ash content by 29.8-35.8% and relatively similar pH values, being neutral to slightly alkaline. The best results were achieved by RH_CNT_600, which was attributed to the nature of RH biomass that is 'cleaner' and richer physicochemically compared to SS that is a waste-derived biomass [Gopinath et al., 2021].

Table 1: Physicochemical characterization of biochar nanocomposites

Sample ID	C_{ORG} (%)	S_{BET} (m^2g^{-1})	Ash (%)	pH
RH_GO_600	51.2	211.8	42.4	6.7
RH_CNT_600	56.0	261.8	34.1	8.2
SS_GO_600	28.5	55.2	60.4	7.9
SS_CNT_600	35.9	53.2	53.1	7.6

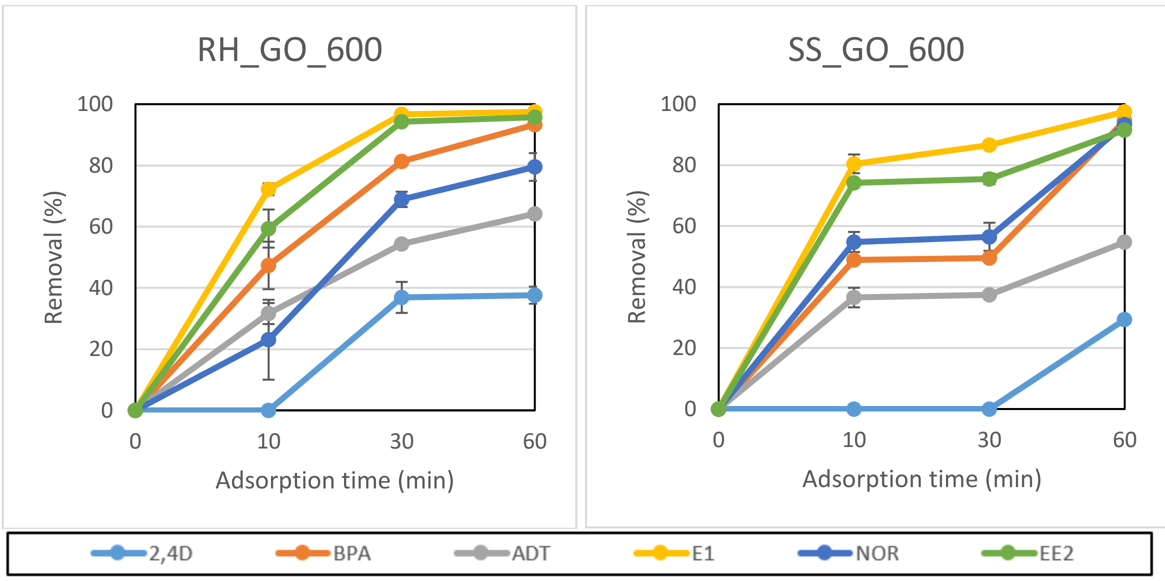

Figure 1: Emerging contaminant adsorption from secondary wastewater effluent on GO-doped biochar nanocomposites

Figure 1 depicts the results concerning the adsorption of six ECs from wastewater on GO-doped biochar nanocomposites. Results showed that all ECs were successfully adsorbed by more than 80% after 60min of adsorption time for both biochar nanocomposites, except for two, ADT and NOR, which were not sufficiently removed (<60%). 2.4D was the most difficult to remove compound, achieving just 37.6% and 29.3% removal after 60min of adsorption time, for RH_CNT_600 and SS_CNT_600 respectively. This was attributed to the chemical nature of this compound, along with the pore blockage that took place in biochar pores [Regkouzas et al., 2023] On the other hand, E1 was the most successfully removed compound, achieving removal higher than 90% after 30min of adsorption time.

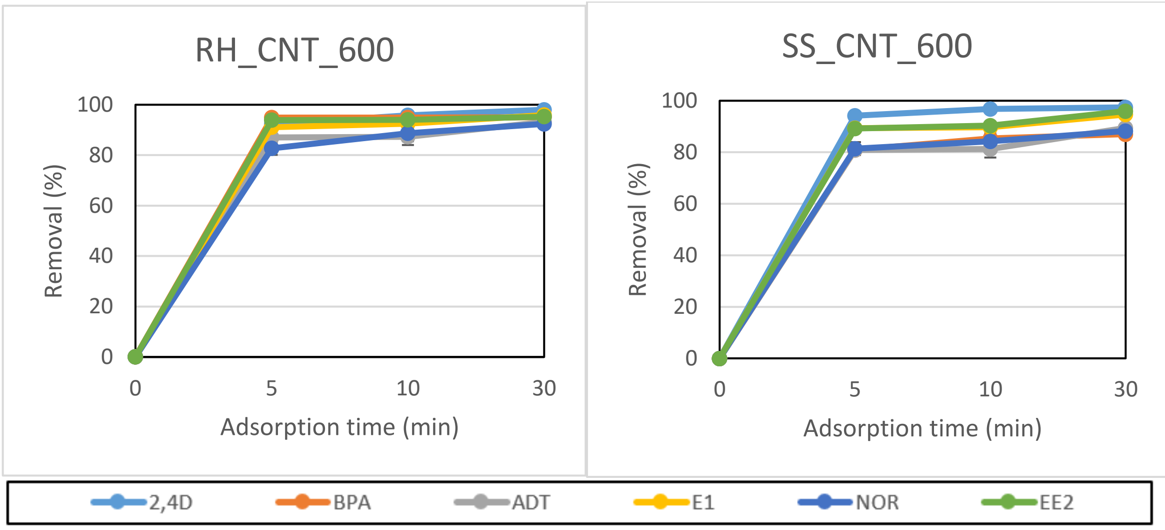

Figure 2: Emerging contaminant adsorption from secondary wastewater effluent on CNT-doped biochar nanocomposites

The results concerning the adsorption of six ECs on CNT-doped biochar nanocomposites from wastewater are presented in Figure 2. In this case, all the investigated pollutants were removed from wastewater in percentages higher than 80% after just 5min of adsorption time. It was also clear that after 5min equilibrium was achieved, making CNT-doped biochar nanocomposites a realistic solution towards the making of integrated adsorbents, capable to antagonize AC, which is their main competitor. This was attributed to the significantly better physicochemical properties of CNTs, that provided more adsorption sites and surface functional groups on biochar surface [Liu et al., 2016].

Conclusion

This work showed that nanomaterial doped biochar can provide an efficient alternative solution in adsorbent market, being able to antagonize AC. The most efficient nanomaterial both physicochemically and based on the adsorption results was CNTs, which when combined with the sustainable biochar technology can provide an efficient and realistic solution for tertiary treatment (filtration) in a WWTP.

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References

Amusat, S. O., Kebede, T. G., Dube, S., & Nindi, M. M. (2021). Ball-milling synthesis of biochar and biochar–based nanocomposites and prospects for removal of emerging contaminants: A review. *Journal of Water Process Engineering*, *41*, 101993. https://doi.org/10.1016/j.jwpe.2021.101993

Ayaz, M., Feizienė, D., Tilvikienė, V., Akhtar, K., Stulpinaitė, U., & Iqbal, R. (2021). Biochar role in the sustainability of agriculture and environment. *Sustainability*, *13*(3), 1330. https://doi.org/10.3390/su13031330

Gopinath, A., Divyapriya, G., Srivastava, V., Laiju, A. R., Nidheesh, P. V., & Kumar, M. S. (2021). Conversion of sewage sludge into biochar: A potential resource in water and wastewater treatment. *Environmental Research*, *194*, 110656. https://doi.org/10.1016/j.envres.2020.110656

Liu, T., Gao, B., Fang, J., Wang, B., & Cao, X. (2016). Biochar-supported carbon nanotube and graphene oxide nanocomposites for Pb (II) and Cd (II) removal. *Rsc Advances*, *6*(29), 24314-24319. https://doi.org/10.1039/C6RA01895E

Ma, M., Xu, D., Zhi, Y., Yang, W., Duan, P., & Wu, Z. (2022). Co-pyrolysis re-use of sludge and biomass waste: Development, kinetics, synergistic mechanism and industrialization. *Journal of Analytical and Applied Pyrolysis*, 105746. https://doi.org/10.1016/j.jaap.2022.105746

Oni, B. A., Oziegbe, O., & Olawole, O. O. (2019). Significance of biochar application to the environment and economy. *Annals of Agricultural Sciences*, *64*(2), 222-236. https://doi.org/10.1016/j.aoas.2019.12.006

Qambrani, N. A., Rahman, M. M., Won, S., Shim, S., & Ra, C. (2017). Biochar properties and eco-friendly applications for climate change mitigation, waste management, and wastewater treatment: A review. *Renewable and Sustainable Energy Reviews*, *79*, 255-273. https://doi.org/10.1016/j.rser.2017.05.057

Regkouzas, P., & Diamadopoulos, E. (2019). Adsorption of selected organic micro-pollutants on sewage sludge biochar. *Chemosphere*, *224*, 840-851. https://doi.org/10.1016/j.chemosphere.2019.02.165

Regkouzas, P., Sygellou, L., & Diamadopoulos, E. (2023). Production and characterization of graphene oxide-engineered biochars and application for organic micro-pollutant adsorption from aqueous solutions. *Environmental Science and Pollution Research*, 1-20. https://doi.org/10.1007/s11356-023-28549-y

Richardson, S. D., & Kimura, S. Y. (2019). Water analysis: emerging contaminants and current issues. *Analytical Chemistry*, *92*(1), 473-505. https://doi.org/10.1021/acs.analchem.9b05269

COFFEE-OIL: PRODUCTION OF BIOCRUDE OIL FROM SPENT COFFEE GROUNDS VIA HYDROTHERMAL LIQUEFACTION

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ABSTRACT

Spent coffee grounds (SPG) are the most significant by-product of coffee brewing and hold a significant percentage of the byproducts from the food/ service industry (Yang et al., 2021). Coffee grounds are industrial bio-waste as well as a source rich in carbon and contain lipids and proteins, components through which many biological-based products can be derived (Zhang et al., 2021). High carbon and phenolic content of SPG, makes them a potential leachate product available in landfills burdening greenhouse gas emissions (Marx et al., 2020). Thus, several practices have been applied for the recovery of phenols from spent coffee grounds via extraction methods (Mussato et al., 2011), but the main solid fraction of the spent coffee grounds is an underutilized resource. This makes it imperative to use alternative and reliable waste treatment technologies such as hydrothermal liquefaction (Yang et al., 2021). Through this process, biomass including coffee grounds are converted into renewable raw material for the production of biofuels and mainly bio-crude oil (Mors and Shiju, 2023).

Hydrothermal liquefaction (HTL) belongs to the category of thermochemical processes that convert high-moisture organic streams into biofuels. The main product from Hydrothermal liquefaction is the bio-crude oil, but HTL products can be found in all three phases, i.e., hydrochar and gases. The process of transmigration of biomass takes place under high temperatures greater than 250°C overcoming water saturation pressure (Ni et al., 2022). The temperatures that hydrothermal liquefaction ranges are mainly between 280°C and 380°C, while the pressures that develop are between 10 and 25 MPa (De Caprariis et al., 2017). During hydrothermal liquefaction, the conversion of biomass is inextricably linked to reactions such as depolymerization, bond breaking, rearrangement and decarboxylation which play a primary role in the breakdown of the solid structure of biomass into bio-crude oil (Ni et al., 2022). Through hydrothermal liquefaction the coffee grounds can be converted into a product with a high calorific value (Marx et al., 2020). Also, bio-crude oil produced from coffee grounds includes high-value chemical products such as fatty acids (Muller et al., 2021). In addition, coffee grounds are high in lipids. This fact plays an important role in the performance and quality of bio-crude oil that is produced. This is because lipids synergistically interact with carbohydrates resulting in a higher yield of bio-crude oil (Yang et al., 2021). In this framework, the scope of the study is the valorization of spent coffee ground via HTL for the production of biofuels and bioproducts.

Spent coffee grounds underwent drying for 24 hours at 105°C for the assessment of the moisture content in accordance with the standard UNI EN ISO 18134-2:2015. The total solids and the volatile solids were measured by following the standard UNI EN 14775:2010 and the heating value of the input and the final products were measured with a Parr 6400 calorimeter and by following the standard UNI EN 14918:2010. The hydrothermal liquefaction experiments were carried out in a CSTR Parr4577A 1L reactor at 300°C and 350°C. For both experiments the input was 40 g of spent coffee grounds and 140 ml of water and the residence time of the material under these conditions was 30 min and the HTL products remained in the reactor for an additional 30 min during the rapid cooling process. This was followed by a series of analyses on the resulting liquid and solid products such as pH, COD (standard: APHA, 1998) and phenols measurement (Folin-Ciocalteu method). The volatile fatty acids were extracted by applying liquid-liquid extraction with isopropanol (1:1) in ultrasonic bath (30 min, 45 °C), centrifugation (10 min, 4000 rpm), filtration (0.22 μm) and distillation. The Long-chain Fatty Acids underwent derivatization into FAMEs as described by Moldoveanu and Victor (2018). The concentration of VFAs and Long-chain Fatty Acids in the

produced biooil were measured in a plasma GC-BID (Shimadzu Nexis 2030) and with the use of the columns J&W Agilent HP – FFAP and MEGA-10 respectively.

The results of the analysis showed that the total VFAs increased from 2005,8 mg/ g COD_{eq} to 2041 mg/ g COD_{eq}, but the pH increased from 4.67 at 300 °C to 5.92 at 350 °C. This can be explained via the implementation of mass balances and the concentration of VFAs. In higher temperatures more gases are produced and the liquid biocrude yields are less in mass comparatively to lower temperatures. Minerals that have very basic pH values are contained in the solid fraction of the products and are partially dissolved in the liquid fraction due to the low relative permeability of water in high pressures. Also, a significant amount of volatile fatty acids was measured at both temperatures. Concentrations of COD and Total Phenols were higher at 300 °C than 350 °C and this is attributed to the increased production of gaseous fuels above 325 °C as shown by Liakos et al. (2023). The higher calorific value of the solid product of hydrothermal liquefaction at 300 °C had a value of 31.9 MJ/Kg while at 350 °C it was 32.9 MJ/Kg. It is observed that carboxylic acids have increased concentrations in increased temperatures, and this explains the increased concentrations of acidic and propionic acids due to the advanced carboxylation processes, and a similar case can be made for the long-chain carboxylic fatty acids like palmitic acid. Overall, the study showed that by means of hydrothermal liquefaction of coffee grounds, high quality bio-crude oil and hydrochar are produced. At the same time, high value molecules are found in the bio-crude oil with the concentrations of volatile fatty acids and long-chain fatty acids being the most interesting.

References:

APHA. Standard Methods for the Examination of Water and Wastewater (twentieth ed.). American Public Health Association. Baltimore, Maryland: Port City Press; 1998.

De Caprariis, B., De Filippis, P., Petrullo, A. and Scarsella, M., 2017. “Hydrothermal liquefaction of biomass: Influence of temperature and biomass composition on the bio-oil production”, Fuel, 208, pp. 618-625. Access: https://doi.org/10.1016/j.fuel.2017.07.054

Liakos, D., Altiparmaki, G., Moustakas, K., Malamis, S., Vakalis, S., 2023. Assessing the products and thermodynamic transitions of hydrothermal treatment of anaerobic sludge. Conference Presentation. 10th International Conference on Sustainable Solid Waste Management. 21-24 June 2023, Chania (Greece).

Marx, S., Venter, R., Karmee, S. K., Louw, J. and Truter, C., 2022. “Biofuels from spent coffee grounds: comparison of processing routes”, Biofuels, 13 (5), pp. 537-543. Access: https://doi.org/10.1080/17597269.2020.1793538

Moldoveanu, S. C. and Victor, D., 2018. Derivatization Methods in GC and GC/MS, InTechOpen.

Mors, J. and Shiju, N. R., 2023. “The synthesis of biooil using ambient pressure liquefaction of organic waste”, Sustainable Chemistry for Climate Action, 2. Access: https://doi.org/10.1016/j.scca.2023.100013

Mussatto, S. I., Ballesteros, L. F., Martins, S., Teixeira, J . A., 2011. Extraction of antioxidant phenolic compounds from spent coffee grounds, Separation and Purification Technology 83, 173-179, https://doi.org/10.1016/j.seppur.2011.09.036.

Ni, J., Qian, L., Wang, Y., Zhang, B., Gu, H., Hu, Y. and Wang, Q., 2022. “A review on fast hydrothermal liquefaction of biomass”, Fuel, 327. Access: https://doi.org/10.1016/j.fuel.2022.125135

Yang, J., Chen, H., Niu, H., McNutt, J. and He, Q., 2021. “A Comparative Study on Thermochemical Valorization Routes for Spent Coffee Grounds”, Energies, 14 (13). Access: https://doi.org/10.3390/en14133840

Yang, J. and Niu, H., 2021. “MW-assisted hydrothermal liquefaction of spent coffee grounds”, The Canadian Journal of Chemical Engineering, 100 (8), pp. 1729-1738. Access: https://doi.org/10.1002/cjce.24270

Zhang, S., Yang, J., Wang, S., Rupasinghe, V. H. P. and He, Q. S., 2021. “Experimental exploration of processes for deriving multiple products from spent coffee grounds”, Food and Bioproducts Processing, 128, pp. 21-29. Access: https://doi.org/10.1016/j.fbp.2021.04.012

Production and characterization of biochar produced from different type of bran

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Keywords: biochar, bran, pyrolysis, European biochar certificate

ABSTRACT

The aim of the research was focused on the production and characterization of biochar prepared from different type of bran. Bran is an outer layer of grains, and it is a side product of milling. It is a mass-produced sustainable material composed both of lignin, cellulose and hemicellulose. The motivation behind this research lies in the need for sustainable waste management strategies in the agricultural sector. Bran, a byproduct of grain processing, is typically underutilized and often considered as waste. General problem of milling industry lies in inefficient utilization of this materials, leading to environmental challenges and missed opportunities for resource recovery. This research aimed to address this issue by investigating the physicochemical properties of the biochar prepared by the pyrolysis under nitrogen atmosphere at 600 °C for 1h. Produced materials were subjected to the standard biochar physiochemical analysis with emphasis on the parameters described in European biochar certificate (EBC). Prepared biochars had a yield of 26% to 34%, consistent with previous findings. Comparing FTIR spectra confirmed adequate pyrolysis. However, the prepared biochars had a small specific surface area, which can be increased through physical or chemical activation. Surface modification is important for industrial use as an adsorbent. The high phosphorus and nitrogen content make biochars suitable for agriculture, enhancing plant production. None of the samples exceeded limits for hazardous elements, but only oat and rye bran biochars met the strictest criteria of the EBC. Rye bran biochar can be used in various sectors, except for the applications requiring high surface area. Oat biochar had low yield and exceeded PAH limits, limiting its use to industry and agriculture with process modifications. Wheat bran biochar meets EBC criteria for agriculture and industry, enhancing plant production in acidic soils. Spelt bran biochar has potential in all sectors, but zinc content restricts it to industrial applications. Rice bran biochar is suitable for agriculture, feed, and industry but exceeds PAH limits for certain categories. The prepared bran materials meet the conditions for being labeled as biochar, and some of the biochars also meet the strictest criteria of the European Biochar Certificate. Bran feedstock proved to be a suitable material for biochar production. Furthermore, it can be assumed that by modifying the pyrolysis process, the quality of the prepared material can be improved to meet even the lowest limits defined by the EBC. This possibility primarily applies to PAH content. By modifying the biochars themselves, the specific surface area and electrical conductivity can be adjusted, rendering the prepared sample a fully functional material suitable for application in agriculture as a fertilizer and feed, or in industry as an adsorbent for organic and inorganic contaminants, or as a component in construction materials, plastics, and textiles.

Acknowledgements

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References:

Sapirstein, H.D. Bioactive Compounds In Wheat Bran. In *Encyclopedia of Food Grains*; Elsevier, 2016; pp. 268-276 ISBN 9780123947864.Stefanakis, A.I., 2018. Constructed Wetlands for industrial wastewater treatment, first ed. John Wiley & Sons Ltd, Chichester, UK.

Activation of persulfate with hydrochar for catalytic degradation of bisphenol A in view of water treatment

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Keywords: Hydrochar; Bisphenol A; Persulfate; Activation; Degradation

ABSTRACT

BPA is considered an EDC due to its significant interference with the metabolism and action of hormones in aquatic organisms (Yu et al., 2020). The presence of BPA in the aquatic environment has potential harm to animal and human health (Li et al., 2021). Therefore, it is necessary to develop an economical and effective method for removing BPA from the effluent of wastewater treatment plant (WWTP).

The application of the advanced oxidation process (AOPs) has attracted much attention for the degradation of organic pollutants in decades (Deniere et al., 2023; Liu et al., 2021). Hydrochar is a novel carbon material used as catalyst and adsorbent noticed by scholars recently (Eskikaya et al., 2023; Zhang et al., 2020). Hydrochar exhibits excellent adsorption capacity for organic matter (Lima et al., 2021; Pauletto et al., 2021). Furthermore, there are abundant oxygen-containing functional groups (OFGs) on the surface of hydrochar, such as hydroxyl, carboxyl and carbonyl, which are considered the main substances to activate persulfate (PS) (Gasim et al., 2022). In addition, during the preparation of hydrochar, persistent free radicals (PFRs) are generated on its surface, which may act as electron donors to produce reactive oxygen species (ROS) to degrade organic pollutants (Yu et al., 2020). Therefore, combining hydrochar with PS might result in synergetic effects for the removal of BPA.

The study seeks to explore its potential for adsorption and degradation of BPA and activation of PS. Therefore, the primary objectives were to investigate the potential of BPA degradation by MPHC activating PS and explore the underlying mechanisms. The experimental parameters which influenced the degradation efficiency of BPA such as initial pH, MPHC dosage, PS dosage, inorganic ions and HA were examined. The predominant reactive free radicals contributed to BPA degradation were identified. The possible degradation mechanisms of BPA within the usage of MPHC/PS were explored.

The results show that MPHC was an efficient absorbent and alternative activator for PS. Increasing the MPHC dosage primarily improved the adsorption of BPA, leading to enhanced removal. It also had a positive effect on the degradation of BPA. Conversely, increasing the PS concentration primarily enhanced the degradation of BPA while reducing adsorption. This resulted in an overall improvement of the removal of BPA from 78.23% to 99.15%. Optimal pH conditions were observed at pH 3 and pH 9 for BPA degradation, while pH 7 favored BPA adsorption. PO43− and NO3− influence adsorption on MPHC but the effect of these anions on MPHC/PS is constrained. Furthermore, the presence of HA had minimal influence on BPA removal by MPHC/PS. The contributions of different reactive species when using MPHC alone to BPA degradation are as follows: electron hole (h+) 2.41%, singlet oxygen (1O2) 7.25%, superoxide radicals (O2• –) 12.86%, electron (e–) 1.84%, hydroxyl radical (•OH) 3.23% and adsorption 47.74%. When using MPHC/PS, more reactive species involved in degradation and the contributions are h+ 2.77%, sulfate radicals (SO4•–) 2.27%, 1O2 19.30%, O2•– 14.56%, e– 1.68%, and •OH 1.28%. Additionally, the performance of MPHC remains stable after three operational recycles. These results highlight the potential

of MPHC as an environmentally friendly material for activating PS and removing organic pollutants, suggesting its promising application in future environmental remediation efforts.

Acknowledgements
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Acute toxicological evaluation of green biocides for outdoor cultural heritage, using *Lactuca sativa* seeds

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Keywords: Biocides, essential oils, acute toxicity, *Lactuca sativa*, culture heritage

ABSTRACT

1. Introduction

Plasters and mortars are commonly used as coatings in external thermal insulation composite systems (ETICS) for building facades. These coatings often contain biocides as active substances to prevent the growth of algae, bacteria, and fungi, thus enhancing the durability of the materials (Vega-Garcia et al., 2020). Biocides are also added to organic coatings used on building facades to protect against biological attacks by algae and fungi (Burkhardt et al., 2012). In the preservation of cultural heritage, there have been proposals to use natural bioactive molecules as potential alternatives to traditional biocides (Isola et al., 2023). While some studies have examined the *in vitro* effects of environmentally friendly biocides, there is limited information on their effectiveness when directly applied and their interactions with historical materials.

Toxicity tests involve comparing the reaction of an organism when exposed to a specific chemical at different concentrations with the reaction of the same organism when not been exposed to the chemical, which is known as the control group (Kress, 2019). These tests are categorized based on the duration of the test, the life stage of the organism, and the specific endpoints being measured. Acute or short-term tests typically involve exposing the organisms for 48 or 120 hours and measure mortality as an endpoint to determine the median lethal concentration (LC_{50}). In the case of this study, the endpoint being considered is the effective concentration (EC_{50}), which refers to the concentration at which individual seeds fail to germinate (U.S. EPA, 2002).

The seed germination test procedure consists of three major steps. Firstly, prepare an aqueous extract of the toxic substance; secondly, incubate seeds with the extract; third, count the germinated seeds (SG) or the relative seed germination (RSG) (Luo et al, 2018). At present, the major problem in the studies of the seed germination tests is that there is no universally adopted procedure, which is reflected at the differences of the corresponding methods if they aren't standardized.

This study tests the toxicity of three new "green" biocides of essential oils of fennel, pennyroyal and rosemary, intended to be used in outdoor heritage to eradicate biofilms. The EC_{50} acute toxicology test with *Lactuca sativa* was carried out to determine the concentration of these "green" biocides that inhibit the germination of 50% of the seeds.

2. Materials and methods

2.1. Experimental design

Exploratory tests were carried out to define the optimized conditions of the following phases tests and to define which ranges of concentration of emulsified essential oils should be used in order to be able to determine the value of the average effective concentration, or the concentration of the essential oils that inhibit the germination of half of the seed population (EC_{50}).

Taking into account the various conditions that were used in similar studies, proceedings and standards consulted during the bibliographic review for the preparation of this study, the optimized conditions in question for this study were the ones that produced longer germinations in control tests performed only with deionized water. Ultra-pure water UPW (pH=6.05) was used for all acute toxicity testing either as

diluter or testing control. All the tested lettuce seeds were pelletized of the species *Lactuca sativa* var. F1 Bataille (Nunhems) with 99-100% germination guaranteed.

In a second phase of exploratory tests, a range of logarithmic concentrations between 5 and 5000 mg/l of the emulsified essential oils were tested to understand which range of arithmetic concentrations should be used to locate the value of the effective concentration for the end point (EC_{50}).

2.2. Acute toxicity test (EC_{50})

All the assays were carried out in Petri dishes with a diameter of 100 mm, with two sheets of Whatman No. 3 filter paper of 90 mm diameter inside. In each Petri dish were sowed 20 seeds of *Lactuca sativa* and a volume of 8 ml of testing solution. The duration of the test was 120 hours. The temperature in de incubator was fixed at 23±1°C, without light cycle. The bottom half of the Petri dishes were sealed with Parafilm to prevent moisture loss during germination. The studied essential oils were previously extracted by hydrodistillation from stems of pennyroyal, fennel and rosemary. The solutions of essential oils were emulsified with a solution of SDS (Sodium Dodecyl Sulphate) at a concentration of 2% (m/v) or approximately 20 g/l.

The essays for the acute toxicity test used solutions of the emulsified essential oils in a range of arithmetic concentrations between 0 and 1400 mg/l in 200 mg/l intervals.

Figure 1 shows the aspect of a Petri dish after sowing the 20 palletized seeds over the two sheets of Whatman nr 3 filter paper, and in 8 ml of testing solution. It also shows, after the 120 hours of the test duration, 6 non-germinated seeds, and 14 germinated seeds with three levels of elongation, about 2, 3 and 4 millimetres. Note that, under the conditions of this study, the total elongation of the germinated control seeds can reach 80 millimetres.

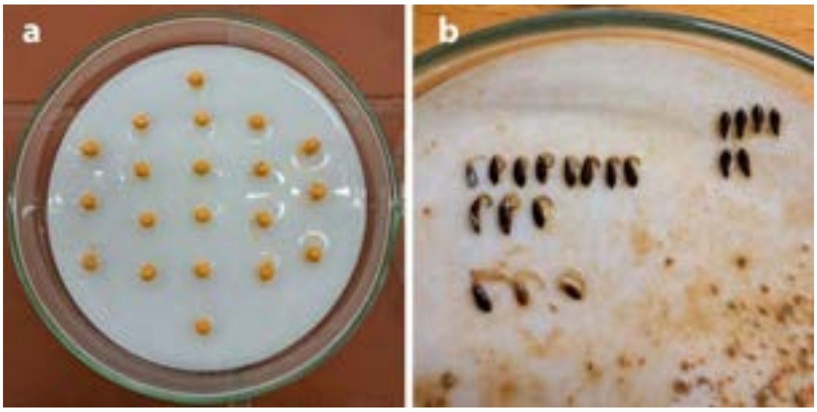


Figure 1 – Process of sowing (a) and counting germinations (b).

2.3. Statistical analysis

The determination of EC_{50} by Litchfield and Wilcoxon method was performed by a linear regression between the concentrations tested and its germination effect, excluding the concentrations with 0% and 100% effect. The fitting of the model obtained (observed versus theoretical expected distributions) was tested by chi-squared test ($\chi 2$) followed by 0-100% table correction of the theoretical expected effect into a new distribution that allow the calculation of the end point and its 95% confidence intervals at 16% and 84% effect (Litchfield & Wilcoxon, 1949; Tallarida & Murray, 1987; Pillai et al, 2021). All the steps needed for the EC_{50} determination were performed using Microsoft 365 (Office) Excel spreadsheet version 18.2.

3. Results and discussion

3.1. Acute toxicity test (EC_{50})

Figure 2 shows the charts of the results of the concentration-effect essays. In the three cases, the essential oils concentrations tested induced the effect of inhibition of gemination that crossed all the spectrum of possible percentual effects: from 0% (0 germinated seed) to 100% effect (20 germinated seeds). This is mandatory to apply the Litchfield-Wilcoxon method.

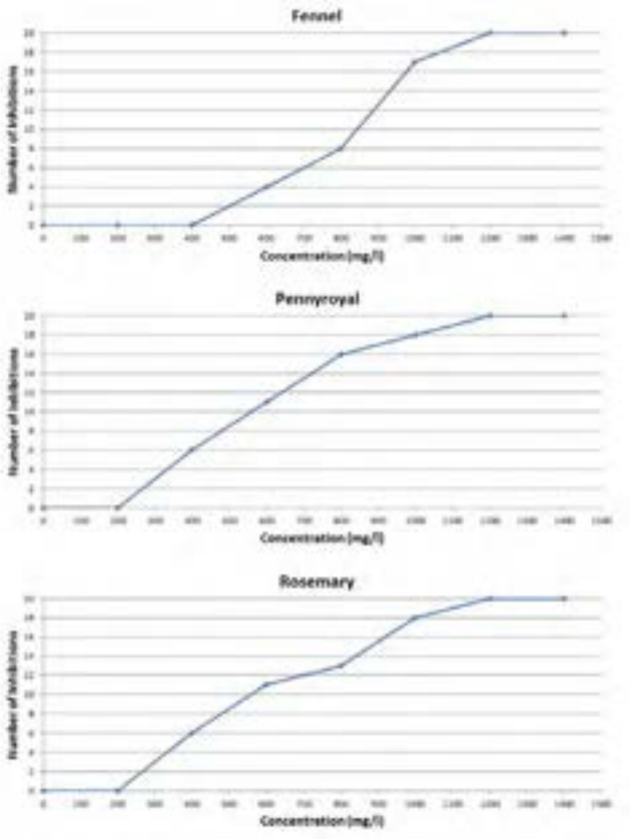


Figure 2 – Number of inhibitions of germination of the *Lactuca sativa* seeds for the essential oils tested (Pennyroyal, Fennel and Rosemary).

Once applied the five steps of the Litchfield-Wilcoxon statistical method, the values of the endpoints (EC_{50}) of the observed effect on germination and its upper and lower limits were calculated with 95% confidence. These results for the three new “green” biocides are shown in Figure 3.

The results revealed that the concentrations that inhibit the germination of the *Lactuca sativa* seeds are higher in the fennel essential oil than for pennyroyal and rosemary. This means that the toxic power of pennyroyal and rosemary essential oils is greater because it achieves the same inhibition results with a lower concentration, and thus, they may be more effective as biocide agents.

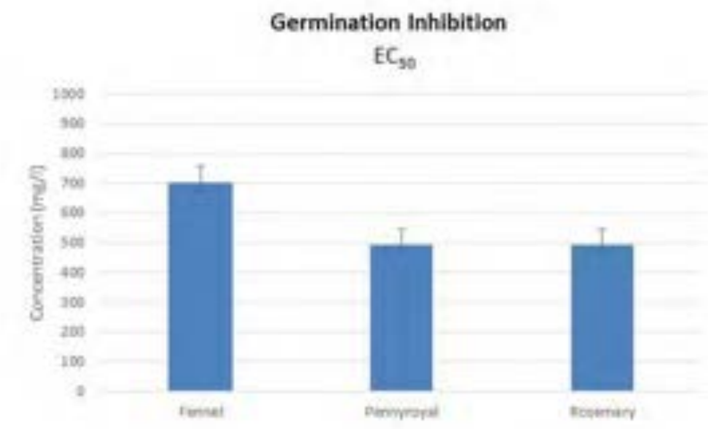
Independentely of the real efficiency of the essential oils as *in situ* biocides for outdoor cultural heritage built in stone and ceramic materials, the results obtained in this acute toxicity test show that, the potential toxic effect for that purpose, is higher and basically the same, for pennyroyal and rosemary by comparison with fennel.

4. Conclusion

The pressure to eradicate biofilms from outdoor heritage built in stone and ceramics has increased lately, especially after the boom of tourism. Tourists and locals tend to associate biofilms with carelessness of the government management of heritage. The search for new biocides that may have less environmental effect is ongoing and this study intends to be another small step on that path.

The results obtained for the acute toxic test EC_{50}, revealed that the concentrations that inhibit the germination of the *Lactuca sativa* seeds is higher for the “green” biocides made with essential oils of pennyroyal and rosemary.

Further research will focus on assessing the ecotoxicological effects and the actual performance when applied *in situ*. Biofilms won't react to the toxic effect of the biocides in the same manner as *Lactuca sativa* seeds, because they are complex symbiotic communities, but this study should be seen as an indicator of the biocidal potential of these 3 new "green" biocides, favouring the decision-taking and the easing of efforts that need to be put in the subsequent phases of the *in situ* testing of these biocides.



	Concentrations (mg/l)		
	Fennel	Pennyroyal	Rosemary
Upper limit	729,1	518,9	519,3
EC_{50}	699,7	492,4	492,8
Lower limit	671,4	467,3	467,7

Figure 3 – Results for EC_{50} and the respective upper and lower confidence interval limits for 95% confidence level.

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References:

Burkhardt, M., Zuleeg, S., Vonbank, R., Bester, K., Carmeliet, J., Boller, M. & Wangler, T. (2012). Leaching of biocides from façades under natural weather conditions. Environmental Science & Technology, 46, pp. 5497–5503. https://doi.org/10.1021/es2040009.

European Parliament, (2012). Regulation (EU) No 528/2012 of the European Parliament and of the Council of 22 May 2012 concerning the making available on the market and use of biocidal products (Text with EEA relevance) Text with EEA relevance: Biocidal Product Regulation (EU) No 528/2012.

Isola, D., Bartoli, F., Municchia, A. C., Lee, H. J., Jeong, S. H., Chung Y. J. & Caneva G. (2023). Green biocides for the conservation of hypogeal mural paintings raised from Western and Eastern traditions: Evaluation of interference on pigments and substrata and multifactor parameters affecting their activity. Journal of Cultural Heritage, 61, pp. 116–126.

Kress, N. (2019). Chapter 6 - Actual Impacts of Seawater Desalination on the Marine Environment Reported Since 2001. Marine Impacts of Seawater Desalination: Science, Management, and Policy. Elsevier. ISBN: 978-0-12-811953-2; DOI: https://doi.org/10.1016/C2016-0-01997-6

Litchfield, J. T. & Wilcoxon, F. (1949). A simplified method of evaluating dose-effect experiments. Journal of Pharmacology and Experimental Therapeutics, 6 (2), pp. 99-113.

Luo Y., Liang J., Zeng G., Chen M., Mo D., Li G., Zhang D. (2018). Seed germination test for toxicity evaluation of compost: Its roles, problems and prospects. Waste Management, 71, pp. 109–114

Tallarida, R.J. & Murray, R.B. (1987). Litchfield and Wilcoxon I: Confidence Limits of ED50. In: Manual of Pharmacologic Calculations. Springer, New York, NY.

DOI: https://doi.org/10.1007/978-1-4612-4974-0_47

U.S. EPA (2002). Short-term Methods for Estimating the Cute Toxicity of Effluents and Receiving Waters to Freshwater Organisms, 5th Edition.

Vega-Garcia P., Schwerda, R., Scherer C., Schwitalla C., Johanna, S., Rommel S. H. & Helmreich B., (2020). Influence of façade orientation on the leaching of biocides from building façades covered with mortars and plasters. Science of the Total Environment, 734, pp. 1-10, 139465

Pillai S. K., Kobayashi K., Mathews M., Thomson Mathai T., Sivakumar B. & Sadasivan P., (2021). John William Trevan's concept of Median Lethal Dose (LD50/LC50) – more misused than used. Journal of Pre-Clinical and Clinical Research. DOI: 10.26444/jpccr/139588

Session C6: Aquatic vegetation systems

A semi-self-sustaining microalgal-bacterial granular sludge process could reduce the cadmium-effect on wastewater treatment efficiency

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Keywords: Microalgal-bacterial granular sludge, Self-sustaining wastewater treatment process, respirometric-titrimetric unit

ABSTRACT

Background

With the increased awareness regarding climate change, carbon footprint, and carbon neutrality, Microalgal-bacterial granular sludge (MBGS) process has gained increasing attention as an emerging wastewater treatment technology. Unlike the conventional activated sludge (CAS) process, MBGS works on a synergistic interaction system that includes microalgal photosynthesis and bacterial respiration. This system achieves a delicate balance in gas exchange, nutrient transformation and fixation, and pollutant removal through assimilation, stripping, nitrification-denitrification, oxidation of organic matter, and adsorption (Gonçalves, Pires, & Simões, 2017). MBGS has advantages such as lower energy consumption, fewer greenhouse gas emissions, high nutrient removal efficiency, and potential resource recovery (Purba et al., 2021). Therefore, MBGS technology is a promising alternative for environmentally sustainable wastewater treatment. However, heavy metals in wastewater could pose a threat to the performance of the MBGS process.

Cadmium, a non-biodegradable metal, can easily accumulate in living organisms even at low concentrations (Chen et al., 2014). Microalgae have the ability to adsorb or integrate with heavy metals, making microalgae-based technologies a potential solution for the sustainable removal of heavy metals (Priya et al., 2022). Nevertheless, Wang et al. (2021) proved that Cd ions could negatively impact the characteristics and performance of MBGS, , compromising the process's ability to remove organic matter and nitrogen. Cd may break the balance between microalgae and bacteria mainly by inhibiting the growth of microalgae (Wang et al., 2021). Therefore, the role of bacteria in wastewater treatment will also be weakened due to the lack of oxygen.

In our study, a semi-self-sustaining microalgal-bacterial granular sludge process was developed to cope with the Cd pollution problem in wastewater treatment. The nutrients and pollutants removal efficiency, characteristics changes, and interaction mechanisms of MBGS were investigated under the stress of Cd ions. It is expected that this study may provide useful information for developing an operating strategy for sustaining the symbiotic relationship between microalgae and bacteria in granules.

Experimental setup

The MBGS used in this study was cultivated by combining activated sludge (obtained from Aquafin Harelbeke, Belgium) and *Chlorella Vulgaris* (obtained from Aquatic Biology Laboratory, KU Leuven, Belgium). After 3 months, the mature and stable MBGS was obtained and can be used in the batch experiment.

Three MBGS-reactors (denoted as RA, RB, and RC) with a working volume of 1 L synthetic wastewater were established in this study: R1 served as the control reactor without any Cd, while R2 and R3 were added with 2 mg/L, 10 mg/L Cd respectively in each cycle. All the reactors were inoculated with the same biomass of MBGS and were operated for 30 days under illuminance of 150 µmol/m2·s with an alternating light/dark mode of 12 h/12 h. The experiments were conducted for consecutive 4 cycles per day, with each cycle

lasting 6 hours and including an aeration time of 1.5 hours. The influent and effluent samples were collected both in the dark phase and light phase.

For the wastewater treatment performance of MBGS, the removal efficiency of kinds of nutrients was measured by Hach test kits (USA). The accumulation of Cd in MBGS was extracted by acid (Zheljazkov & Nielsen, 1996) and further analyzed by ICP-OES (iCap 7000 Series Thermo Scientific, USA).

For the characters of MBGS, the MLSS, SVI5, and concentration of Chl *a* were determined by the standard methods (APHA., 2005). The extracellular polymeric substances from MBGS were extracted by thermal method (Zhang et al., 2020). Furthermore, a spectrofluorophotometer (RF-5301PC Shimadzu, Japan) and an FTIR spectrometer (Nicolet, USA) was applied for the analysis of the components. A combined respirometric-titrimetric unit was used at the end of the experiment for the description of the microalgal-bacterial activity.

Results

The effect of Cd^{2+} on the performance of MBGS was illustrated in Fig.1. After 30 days of exposure, there is no significant difference between the control group and treatment groups. These semi-self-sustaining reactors demonstrated excellent COD and NH_4-N treatment efficiencies during both light and dark phases. However, the removal efficiency of T-N was consistently higher in the light phase compared to the dark phase. With the accumulation of toxicity, the reactors with Cd^{2+} had a significantly negative effect on the T-N removal rate in a concentration-dependent manner.

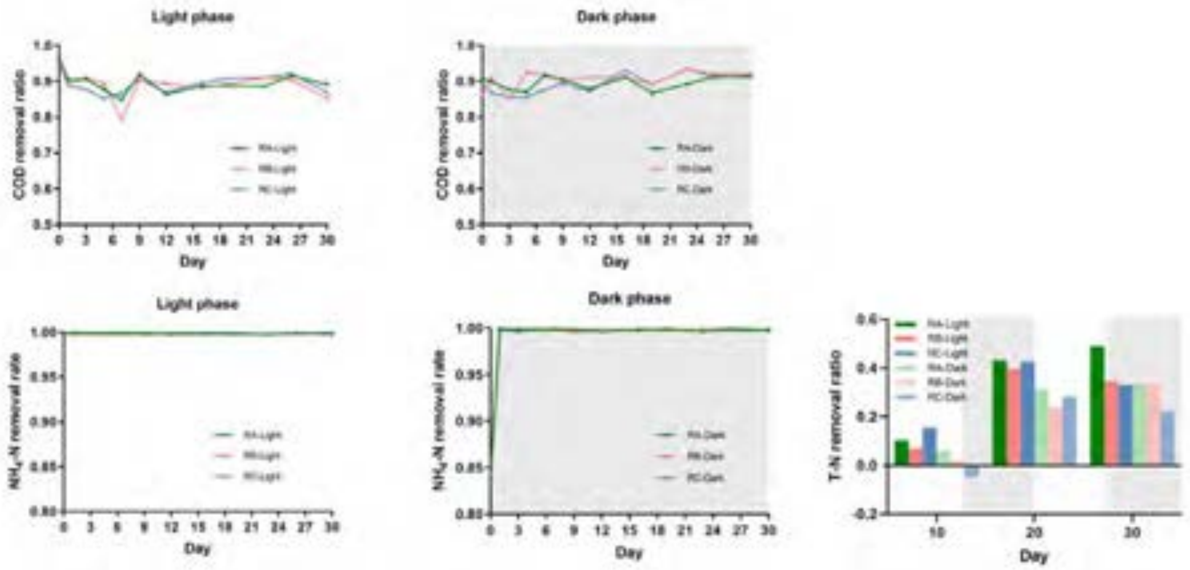
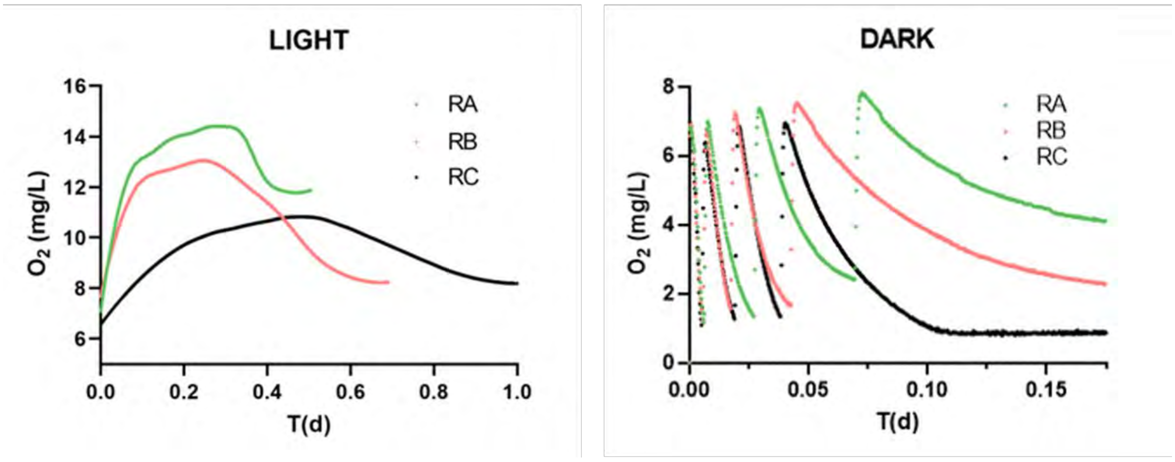


Fig. 1. Removals of COD, NH_4-N, and T-N in the presence of different Cd^{2+} concentrations under light phase and dark phase.

Furthermore, it is worth noting that heavy metal biosorption can occur in MBGS through mechanisms such as physisorption, chelation, and complexation, which can help to remove heavy metals from contaminated water (Souza et al., 2012). This study proved that the Cd content in MBGS reached 2.23 mg/g dry weight and 7.92 mg/g dry weight after 30-day exposure at the Cd^{2+} concentration of 2 mg/L and 10 mg/L, respectively.

Although the nutrient removal performance of semi-self-sustaining MBGS was not affected compared with self-sustaining MBGS (Wang et al., 2021), the characteristics of MBGS with 10 mg/L Cd were significantly changed after 30-day exposure period. The SVI_5 of RA, RB, and RC changed from 35.73 to 64.85, 65.32, and 55.95 mL/g, respectively. Correspondingly, the Chl *a* of B and C reduced by 19.46% and 26.11% compared to RA. In addition, the stress-induced production of extracellular polymeric substances (EPS) in MBGS. The higher Cd^{2+} concentration of 10 mg/L could stimulate MBGS to secrete more protein and humic acid, which accumulated over time. FTIR analysis revealed that carboxyl groups in EPS-PN were the major binding sites for Cd^{2+} adsorption by MBGS.

In order to evaluate the effect of Cd^{2+} on the symbiosis and ability of MBGS, the dissolved oxygen (DO) and pH were continuously monitored and controlled by a combined respirometric-titrimetric unit, and the biomass was the same in each reactor. The results are shown in Fig. 2, they presented different oxygen production rates and oxygen uptake rates in each reactor. In the light phase, inorganic carbon was the only



carbon source in the system. It is noticed that microalgae in RA had a stronger ability to produce oxygen than RB and RC, which is corresponding to the results of Chl *a* content. However, during the dark phase, when organic carbon was the only carbon source, bacteria in RC consumed oxygen faster than those in RA and RB.

Fig. 2 Comparison of the measured respirometric profiles of the photoautotrophic (light phase) and heterotrophic (dark phase) experiments among RA, RB, and RC.

Based on the findings, it can be concluded that EPS and microalgae effectively retained most of the Cd^{2+}, which may have prevented further penetration into the MBGS granules. However, since microalgae form the outer layer of the MBGS structure, they are more susceptible to Cd-induced stress than bacteria. This may lead to insufficient oxygen supply, which can affect bacterial activity. Previous studies have shown that microalgae and bacteria primarily assimilate inorganic nitrogen in wastewater instead of relying on conventional nitrification and denitrification processes. On the other hand, soluble organic matter is mainly utilized by bacteria (Abouhend et al., 2018; Abouhend et al., 2020). When exposed to a Cd-contaminated environment, additional aeration can improve the dominant role of bacteria in the semi-self-sustaining MBGS process. However, it is still worth exploring ways to enhance the assimilation and fixation of carbon, nitrogen, and phosphorus by microalgae.

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references

Ahmad, SR, and DM Reynolds., 2005. Standard methods for the examination of water and wastewater. Washington DC: American Public Health Association (APHA), USA.

Abouhend, A. S., McNair, A., Kuo-Dahab, W. C., Watt, C., Butler, C. S., Milferstedt, K., . . . Park, C. (2018). The Oxygenic Photogranule Process for Aeration-Free Wastewater Treatment. *Environ Sci Technol, 52*(6), 3503-3511. doi:10.1021/acs.est.8b00403

Abouhend, A. S., Milferstedt, K., Hamelin, J., Ansari, A. A., Butler, C., Carbajal-Gonzalez, B. I., & Park, C. (2020). Growth Progression of Oxygenic Photogranules and Its Impact on Bioactivity for Aeration-Free Wastewater Treatment. *Environ Sci Technol, 54*(1), 486-496. doi:10.1021/acs.est.9b04745

Chen, H. B., Wang, D. B., Li, X. M., Yang, Q., Luo, K., Zeng, G. M., & Tang, M. L. (2014). Effects of Cd(II) on wastewater biological nitrogen and phosphorus removal. *Chemosphere, 117*, 27-32. doi:10.1016/j.chemosphere.2014.05.057

Gonçalves, A. L., Pires, J. C. M., & Simões, M. (2017). A review on the use of microalgal consortia for wastewater treatment. *Algal Research, 24*, 403-415. doi:10.1016/j.algal.2016.11.008

Priya, A. K., Jalil, A. A., Vadivel, S., Dutta, K., Rajendran, S., Fujii, M., & Soto-Moscoso, M. (2022). Heavy metal remediation from wastewater using microalgae: Recent advances and future trends. *Chemosphere, 305*, 135375. doi:10.1016/j.chemosphere.2022.135375

Purba, L. D. A., Abdullah, N., Yuzir, A., Zamyadi, A., Shimizu, K., & Hermana, J. (2021). Rapid Development of Microalgae-Bacteria Granular Sludge Using Low-Strength Domestic Wastewater. *Journal of Water and Environment Technology, 19*(2), 96-107. doi:10.2965/jwet.20-132

Souza, P. O., Ferreira, L. R., Pires, N. R. X., S. Filho, P. J., Duarte, F. A., Pereira, C. M. P., & Mesko, M. F. (2012). Algae of economic importance that accumulate cadmium and lead: a review. *Revista Brasileira de Farmacognosia, 22*(4), 825-837. doi:10.1590/s0102-695x2012005000076

Wang, S., Ji, B., Cui, B., Ma, Y., Guo, D., & Liu, Y. (2021). Cadmium-effect on performance and symbiotic relationship of microalgal-bacterial granules. *Journal of Cleaner Production, 282*. doi:10.1016/j.jclepro.2020.125383

Zhang, B., Li, W., Guo, Y., Zhang, Z., Shi, W., Cui, F., . . . Tay, J. H. (2020). A sustainable strategy for effective regulation of aerobic granulation: Augmentation of the signaling molecule content by cultivating AHL-producing strains. *Water Res, 169*, 115193. doi:10.1016/j.watres.2019.115193

Zheljazkov, V. D., & Nielsen, N. E. (1996). Effect of heavy metals on peppermint and cornmint. *Plant and Soil, 178*(1), 59-66. doi:10.1007/BF00011163

Assessing Contaminants of Emerging Concern, Heavy Metals, and Pathogens in Wastewater-Grown Microalgae for Agricultural Applications

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ABSTRACT

In this study, lettuce crops were fertilized with microalgal biomass grown in wastewater. The biomass was analyzed for pathogens and heavy metals and compared the values to the threshold set by EU regulation for fertilizing products. The study also monitored the presence of contaminants of emerging concern (CECs) in wastewater, microalgal biomass and lettuce leaves. The biomass had pathogens and heavy metals content below the regulation limit. The agronomic test demonstrated that microalgal biomass can reduce the need of mineral nitrogen fertilizer while providing lettuce with similar fresh weight. Different CECs were found in wastewater, in total 25 compounds, whereas microalgal biomass presented only 3 of them, at concentrations ranging 0.1 to 25 $\mu g/g_{DM}$. Lettuce leaf samples presented concentrations of cadmium and some CECs, but their source could not be attributed to the microalgal fertilizer.

INTRODUCTION

Wastewater can be a sustainable nutrient source for the cultivation of microalgae while reducing the costs of the process. Moreover, the biomass could be further used as biofertilizer (Ronga et al., 2019). However, in addition to providing nutrients, wastewater can potentially present contaminants such as pathogens, heavy metals and other microcontaminants. Therefore, it is necessary to evaluate the fertilizing properties of microalgal biomass cultivated in wastewater in lettuce crops while assessing its compliance with the limits reported in the European legislation about fertilizing products (European Union, 2019). Moreover, different organic contaminants, such us pharmaceutical products, were identified and quantified in wastewater, microalgal biomass and lettuce samples.

MATERIAL AND METHODS

Characterization of microalgal biomass

Real municipal wastewater was treated in two high rate algal ponds (HRAPs), with a volume of 470 L each, located outdoors in Barcelona (Spain). The microalgal biomass was first harvested in secondary settling tanks and then it was centrifuged, obtaining a paste that was frozen at -20°C.

Prior to the agronomic assay, the biomass was totally thawed and analyzed. First, macro- and micronutrients (nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), sulphur (S), iron (Fe), sodium (Na)). Then, pathogens ((*Salmonella*, *Escherichia coli, Legionella* spp. and *Legionella* *pneumophila*); heavy metals (cadmium (Cd), cupper (Cu), chromium (Cr), hexavalent chromium (Cr(VI)), mercury (Hg), nickel (Ni), lead (Pb), zinc (Zn), aluminium (Al), arsenic (As)) and contaminants of emerging concern.

Agronomic assay

Lettuce (*Lactuca sativa* L. cv Maravilla) was used to study the agronomic properties of the microalgal biomass. The assay took place in a greenhouse, located in Castelldefels (Barcelona, Spain) between November and January, using 2L pots. Four treatments were tested: (C-) negative control without fertilizer; (C+) positive control with NPK 100% inorganic; (M1) microalgal biomass + inorganic N (half dose of C+) + inorganic PK (same dose as C+); (M2) microalgal biomass + inorganic PK (same dose as C+). Each treatment consisted in 30 pots. Fresh weigh was recorded after 9 weeks. Lettuce leaf samples were analysed to quantify the macro- and micronutrients as well as the content of heavy metals. Additionally, contaminants of emerging concern were monitored in wastewater, microalgal biomass, and lettuce leaves. Once lettuces were harvested, a leachates assay was performed. For this, 1L of tap water was added to each pot and the leachate was analysed for nutrients (nitrate, ammonium and phosphate).

RESULTS AND DISCUSSION

Biomass characterization

The microalgal biomass presented a NPK ratio of (1:0.25:0.05), being the nitrogen the nutrient accumulated the most (6.69 %DM). These results are in accordance with previous studies (Álvarez-González et al. 2022) . Table 1 shows the content of pathogens and heavy metals, as well as the threshold of the European regulation. In general, the concentration is below the limit, except for Cd, (3.10 mg/kgDM when the limit for organo-mineral fertilizers is 3 mg/kgDM).

Microalgal biomass as biofertilizer: effects in lettuce growth

The findings of the agronomic assay indicated that M1, combining the microalgal biomass with inorganic fertilizer, showed similar shoot fresh weigh than the positive control, C+. The values were recorded as 95.41 g/plant for C+ and 93.45 g/plant for M1 (Table 2), with no significant differences ($p < 0.05$). Although M2, with no addition of inorganic N, reported lower weight (43.7 g/plant) than C+ and M1, it was higher than the negative control, C-. Therefore, these results may indicate that a part of the mineral N can be replaced with microalgal biomass, with no impacts in the weight.

The lettuce leaf samples were analyzed for nutrients, revealing that C+ and M1 presented similar content for N and K (Table 2), which further supports the earlier findings. Furthermore, P and S content were higher in M1 than C+, with a respective increase of 37% and 20%. The nutrient content in M2 was in general lower, indicating that the amount of microalgal biomass was not enough to support lettuce's growth.

Cadmium was the only heavy metal measured in lettuce leaves, as this element was exceeded the European limit. However, no significant differences were observed between C+, M1, and M2. This result demonstrates that the source of the metal in lettuce leaves was not associated with the biomass, but likely to the soil, which contained 0.5 mg/kg_{DM} of Cd.

Contaminants of Emerging Concern: possible transfer to lettuce crops

A few CECs, caffeine, diclofenac, hydrocynamic acid, methyl dihydrojasmonate, and naproxen, presented a concentration higher than 3 µg/L in wastewater (Figure 1). On the other hand, microalgal biomass only presented 3 compounds (hydrocinnamic acid, caffeine, and bisphenol A) with concentrations higher than the LOQ (Limit Of Quantification). Although a few CECs were also detected in leaves samples, their source could not be linked to the microalgal biomass, as both the positive and negative controls also presented the compounds.

Nutrient leaching from microalgal-based biofertilizer

The leaching assay revealed that there were differences in the concentration of N species among treatments (Table 3). Surprisingly, the concentration of nitrate and ammonium were difference between

C+ and M1, despite receiving the same amount of ammonium nitrate 23 days prior to harvest. For instance, C+ presented 128 mg/L N-NO3- and 3 mg/L N-NH4+ whereas M1 presented 204 mg/L N-NO3- and < 0.2 mg/L N-NH4+. This result may indicate that the addition of microalgal biomass could modify the oxidation of ammonium to nitrate, either by promoting bacterial growth or by adding bacteria to soil.

All treatments (except C-) were provided with the same dose of P at the beginning. However, only C+ presented a concentration of P higher than LOQ in leachate (5 mg/L P-PO_4^{3-}). This can suggest that microalgal biomass can avoid P leaching.

Table 1. Content of heavy metals (mg/kgDM) and pathogens (CFU/g) in the microalgal biomass cultivated in wastewater. Third column shows the threshold value given in European regulation (EC 2019/1009) for mineral-organic fertilizers.

Heavy metal (mg/kg$_{DM}$)	**Microalgal biomass**	**European regulation limits**
Cadmium	3.10	3
Hexavalent chromium	1.31	2
Mercury	0.52	1
Nickel	< 46.5	50
Lead	< 46.5	120
Arsenic	< 18.6	40
Copper	279	600
Zinc	437	1500
Pathogens (CFU/g)	**Microalgal biomass**	**European regulation limits**
Legionella ss	Not detected	-
Salmonella spp	Not detected	Absence
Escherichia coli	400	1000

Table 2. Fresh weight (g/plant) and nutrient content (%DM) in the four treatments: C- (negative control), C+ (positive control), M1 (microalgal biomass with N supplement), M2 (microalgal biomass). Standard Error of the Mean is given in brackets (n=30 for fresh weight and n=4 for nutrients). Different letters indicate significant difference ($p < 0.05$).

	C-	**C+**	**M1**	**M2**
Fresh weight (g/plant)	28.28^{c} (0.93)	95.41^{a} (3.53)	93.45^{a} (3.21)	43.7^{b} (1.14)
N (%$_{DM}$)	0.88^{b} (0.03)	3.60^{a} (0.08)	3.69^{a} (0.03)	1.01^{b} (0.02)
P (%$_{DM}$)	0.14^{c} (0.01)	0.18^{bc} (0.01)	0.28^{a} (0.02)	0.19^{b} (0.01)
K (%$_{DM}$)	2.12^{c} (0.07)	5.04^{a} (0.10)	5.24^{a} (0.17)	3.24^{b} (0.09)
S (%$_{DM}$)	0.10^{a} (0.01)	0.24^{c} (0.01)	0.29^{d} (0.01)	0.14^{b} (0.01)

Table 3. Soluble inorganic nutrients concentrations (Ammonium; Nitrate; Phosphate) in the leachate in each treatment: C- (negative control), C+ (positive control), M1 (microalgae biomass with N supplement), M2 (microalgae biomass). Standard Error of the Mean is given in brackets (n=4).

	C-	**C+**	**M1**	**M2**
N-NH_4^+ (mg/L)	<0.02	2.7 (0.6)	<0.2	<0.02
N-NO_3^- (mg/L)	3.0 (0.3)	127.8 (5.5)	204.1 (14.4)	4.4 (0.6)
P-PO_4^- (mg/L)	<0.8	5.4 (1.7)	<0.8	<0.8

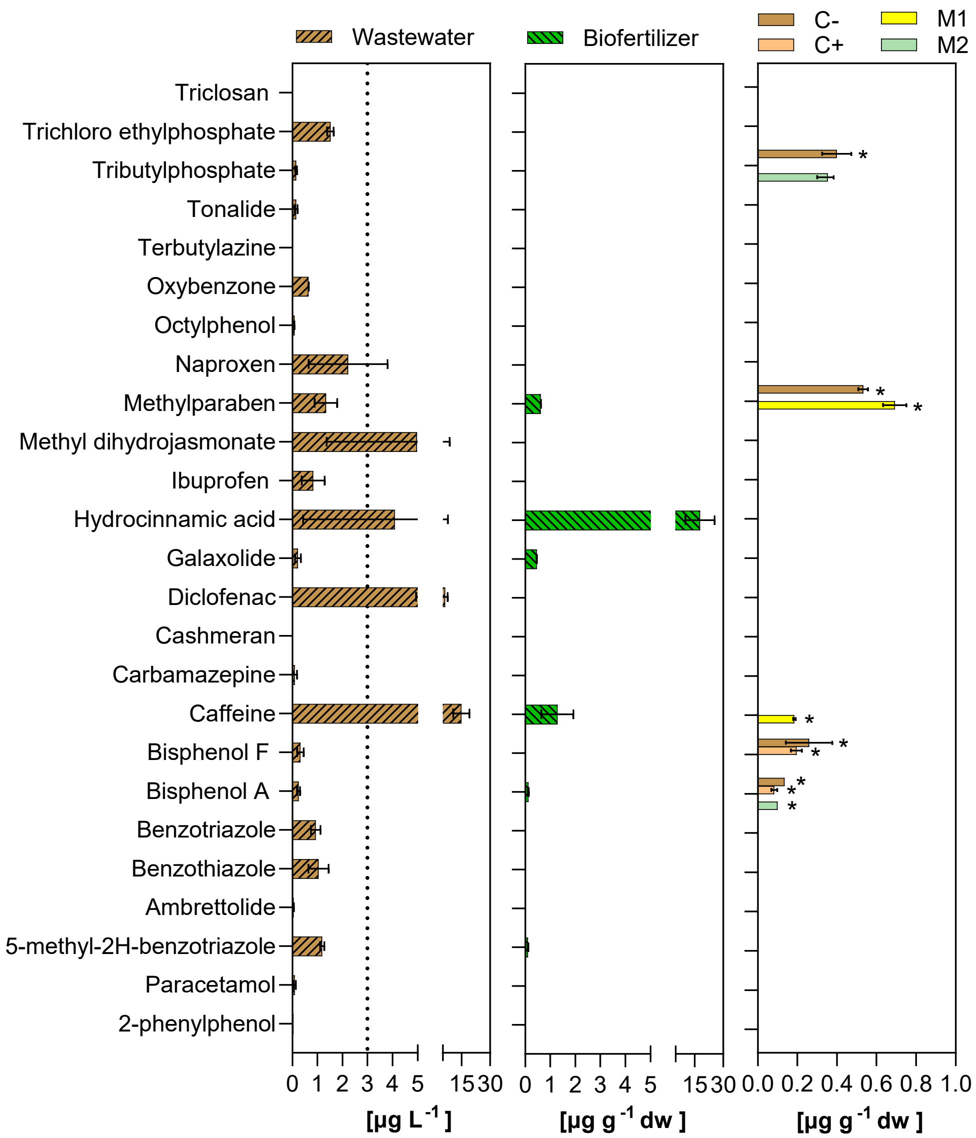

Figure 1. Mean concentrations of the detected CECs (25 out of 29) in the wastewater (n=2), biomass (n=2) and lettuce leaves of each treatment (C-, C+, M1 and M2) (n=4). Values are given in µg/L for water and µg/dDW for biomass or lettuce. Compounds with concentration <LOD in all samples are not plotted. Only replicates with values >LOD were used to calculate means. Error bars show the range of the measurements. *Compounds were detected on two or less replicates.

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References:

Álvarez-González, A., Uggetti, E., Serrano, L., Gorchs, G., Ferrer, I., Díez-Montero, R., 2022. Can microalgae grown in wastewater reduce the use of inorganic fertilizers? J. Environ. Manage. 323, 116224. https://doi.org/10.1016/j.jenvman.2022.116224

European Union 2019. Regulation (EU) 2019/1009 of the european parliament and of the council 2019 laying down rules on the making available on the market of EU fertilising products and amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009 and repealing Regulation (EC) No 2003/2003.

Ronga, D., Biazzi, E., Parati, K., Carminati, D., Carminati, E., Tava, A. 2019. Microalgal Biostimulants and Biofertilisers in Crop Productions. Agronomy 9, 192. https://doi.org/10.3390/agronomy9040192

Algal technologies for green products – preliminary microbiological examination

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Keywords: algae, wastewater, reclaimed water, fertilizer, multi-drug resistant bacteria, contaminants of emerging concern

ABSTRACT

Introduction

Growing urbanization, increasing resource consumption, climate changes, and the transition to a low carbon society require increasing flexibility of the communal infrastructure and integrated water resource management at all levels by 2030 (SDG6 and SDG13, United Nations, 2015). The EU's response to the rational use of some resources is to limit abstractions of surface and ground water, reduce the impact of the treated wastewater (WW) discharges into water bodies, and promote water and nutrient saving through the use of reclaimed water, while ensuring a high level of environmental protection. The use of reclaimed water can be problematic for the environment and public health due to contaminants of emerging concerns (CEC), microplastics, pathogens, multi-drug resistant bacteria (MDR) (Manyuchi et al., 2018). The Scientific Committee on Health, Environmental and Emerging Risks (SCHEER) identified 14 emerging issues that could impact on human health or the environment in the future (SHEER, 2018). Two of these issues are persistent, mobile, and toxic substances and chemicals in recycled streams (an issue of circular economy) having the highest overall prioritisation scores which calls for the development of safe use of reclaimed water. Moreover, the EU Regulation on use of reclaimed water in agriculture (EU Parliament, 2020) was amended in 2020 for microbiological, pharmaceutical, pesticides and microplastics risks, but it does not yet specify all compounds that need to be monitored to avoid those risks.

The European Commission (European Commission, 2015) has identified nature-based solutions (NBS) as a plausible means of preserving ecosystem balance and they can be applied for soil health, carbon mitigation, downstream water quality protection, biodiversity benefits as well as assisting agricultural production and supply chains to achieve net-zero environmental emissions while achieving food and water security and meeting climate goals (Miralles-Wilhelm, 2021). Algal technologies as one of several NBS are experiencing interesting advancements in the field of WW treatment (e.g., CEC, pathogens, nutrients) and simultaneous resource recovery for agricultural use. This calls for the development and scientific evaluation of the potential of algal technologies for the production of green products (e.g., reclaimed water, algal biomass, organic fertilisers, green mulch, biostimulants) and minimizing potential environmental and health risks.

Algal technologies represent an environmentally friendly alternative to conventional activated sludge treatment of WW for removal of nutrients, organics, heavy metals and pathogens (Renuka et al., 2015). They can tolerate high load WW (Wang et al., 2015) which can be used as a low-cost nutrient source for algae cultivation (Solovchenko et al., 2016). A high-rate algal pond (HRAP) is the most common full-scale application of algal WW treatment systems (Craggs et al., 2012). Compared to conventional activated sludge treatment, HRAP requires a large surface area to assure proper light availability for algae growth and long hydraulic retention times (up to 20 days) that encourage algal biomass growth and nutrient recovery, while requiring a lower energy input (Park et al., 2011). Algal biomass has potential applications in energy production, polymers and most notably in agriculture (Park and Craggs, 2011).

In this contribution we will present the concept of a new national research project on algal technologies for green products and preliminary results of the project's first phase. The core of the projects is a research of closed-streams concept based on algal technology, in lab scale photobioreactors and in a pilot scale

HRAP, to produce green products based on two matrices: 1) water and 2) biomass. The main aim of the research is to evaluate environmental and health risks of green products such as water for irrigation, organic fertilisers, green mulch, and biostimulants, based on existing legislation and compared to products of conventional WW treatment technologies.

Materials and methods

The research in conducted at laboratory, pilot and field scale and is organised into 5 work packages (Figure 1) following specific objectives:

- **On the technology level**: achieve adequate removal of nutrients, pathogens, heavy metals, microplastics, CEC, and MDR bacteria, and optimise algal biomass harvesting by design and performance optimisation of algal technologies and advanced oxidation processes for WW treatment, disinfection, and harvesting, developed in lab-scale, and validated on pilot-scale.
- **On products level**: produce (1) reclaimed water for irrigation, (2) organic fertilisers from algal biomass for increased soil water retention and erosion prevention by production of different green products (composted algal biomass in combination with reed and willow wood chips, processed biomass for biostimulants' isolation). Their safety, in terms of heavy metal and pathogen content, and additionally microplastics, CEC, and MDR bacteria, will be evaluated and compared to products of conventional WWTP.
- **On closed-loop level**: define environmental and health risks of green products and propose additional legislative limits for their safe (re)use in agriculture by monitoring important potential environmental and health risks, currently not specified in legislation, such as microplastics, CEC, and MDR bacteria in different compartments (water, biomass, organic fertilisers).

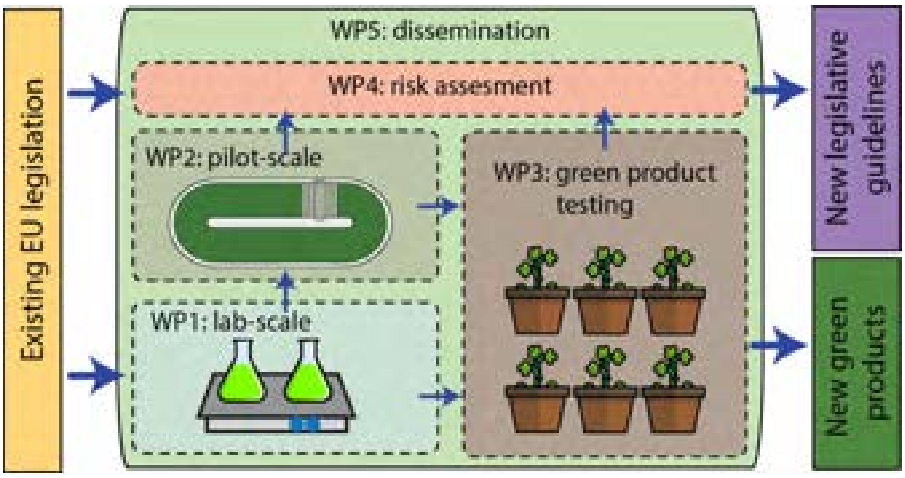

Figure 1: Structure of the project.

The pilot HRAP is installed at the central wastewater treatment plant (WWTP) in Ajdovščina, Slovenia (45◦52′32′′N 13◦54′20′′E) and treated mechanically pre-treated municipal WW. The HRAP volume is 3 m^3 and the surface area is 12.7 m^2. Mixing is provided by a paddlewheel. HRAP is fed with WW from the primary settler of the WWTP and is in operation since 2018. It was inoculated with *Chlorella vulgaris* and native microalgae and bacteria (Škufca et al., 2021b). The HRAP is operated in a semi-continuous manner, i.e., twice per week, 10% of its volume is transferred to an algae settler. Algae sedimentation is enhanced by ultrasound transducer (range 50 m, power 12 W, with dual core multi frequency technology, 20–200 kHz, LG SONIC, The Netherlands) based on positive experience from previous research (Bulc et al., 2011). An equal amount of fresh influent is then added to the pond.

Currently, in WP1, we compared the HRAP performance with conventional activated sludge WW treatment system samples. The samples were taken from different treatment stages within the central WWTP Ajdovščina: (1) inflow to WWTP and HRAP (primary treated municipal WW), (2) aeration tank of WWTP, (3) HRAP, (4) outflow HRAP, (5) outflow WWTP, and (6) HRAP biomass. Each sample was taken in a sterile bottle and transported in a cold chain to the laboratory of the Faculty of Health Sciences in Ljubljana. Preliminary microbiological examination of the samples included detection of the number of different groups of microorganisms and their identification and preliminary screening for antibiotics by the presence of inhibitory substances with BR test (Brilliant Black Reduction Test; AiM GmbH, Germany) in BetaStar® combo test to determine ß-lactam antibiotics (Neogen, USA). The monitoring of CEC (pharmaceuticals, personal care products and/or bisphenols) will be further expanded according to our previous research where identification method for bispehonol was developed (Škufca et al., 2021a) and where we proved that mixed algae-bacteria biomass in HRAP can remove spiked CEC (Prosenc et al., 2021).

In the project, HRAP is optimized to increase biomass production and efficient harvesting during the WW treatment process. Next, different green products from algal biomass will be developed and tested including direct fertigation, slow-release fertilizers, and bio soil amendments. Additionally, treated WW will be used for irrigation.

Results and discussion

The preliminary microbiological examination (Table 1) expectedly showed better removal of coliforms, *E. coli* and enterococi in HRAP compared to outflow from central WWTP. This can be explained by longer retention time and higher impact of solar radiation to a shallow water depth in HRAP compared to 4 m deep aeration tanks of conventional WWTP (Craggs et al., 2014). Consequently, also the number of total colony count per mL at 22 and 37 °C was one to two orders of magnitude lower in HRAP compared to WWTP aeration tank. The number of fungi was three orders of magnitude higher in WWTP aeration tank compared to HRAP.

Table 1: Presence of different bacteria and fungi at different sampling points of high-rate algae pond and central WW treatment plant Ajdovščina in colony forming units per mililiter (CFU/mL).

	TCC* at 22°C	TCC at 37°C	Coliforms	*E. coli*	*Enterococcus* spp.	*Pseudomonas* spp.	Fungi	*Staphylococcus* spp./*Micrococcus* spp.	*Clostridium* spp.	*Bacillus* spp.
Inflow	$3.7 \cdot 10^6$	$4.1 \cdot 10^6$	$1.2 \cdot 10^6$	$3.4 \cdot 10^5$	$6.4 \cdot 10^3$	20	$1.6 \cdot 10^3$	$1.2 \cdot 10^3$	$1.6 \cdot 10^3$	$4.0 \cdot 10^3$
Aeration	$2.7 \cdot 10^6$	$8.1 \cdot 10^5$	$6.2 \cdot 10^5$	$3.2 \cdot 10^3$	$3.3 \cdot 10^3$	10	$5.6 \cdot 10^3$	$2.2 \cdot 10^3$	$3.0 \cdot 10^3$	$6.2 \cdot 10^3$
Outflow WWTP	$3.7 \cdot 10^5$	$1.8 \cdot 10^5$	$5.7 \cdot 10^4$	$2.2 \cdot 10^3$	$2.6 \cdot 10^2$	1	68	1.8	25	$1.8 \cdot 10^3$
HRAP	$2.0 \cdot 10^4$	$1.8 \cdot 10^4$	$8.4 \cdot 10^3$	0	2	<10	58	70	$1.8 \cdot 10^2$	$2.1 \cdot 10^2$
Outflow HRAP	$1.5 \cdot 10^5$	$<10^4$	$1.0 \cdot 10^3$	0	0	<10	74	3	41	$1.9 \cdot 10^2$
Algae biomass	$6.3 \cdot 10^5$	$1.7 \cdot 10^5$	$5.2 \cdot 10^4$	$1.0 \cdot 10^2$	$4.6 \cdot 10^2$	$3.8 \cdot 10^2$	52	$1.8 \cdot 10^3$	$3.0 \cdot 10^3$	$6.0 \cdot 10^3$

*TCC - total colony count

Regarding microorganisms, the EU regulation (2020/741) defines the limiting value only for *E. coli* and in specific cases *Legionella* spp. With no detected *E. coli* in the outflow from HRAP, the water complies with quality class A which means it can be used to irrigate all food crops consumed raw where the edible part is in direct contact with reclaimed water and root crops consumed raw and all irrigation methods can be applied. However, other limiting parameters have to be met as well (BOD_5 < 10 mg/L, TSS ≤ 10 mg/L and turbidity 5 ≤ NTU), which might be more challenging for HRAP due to difficult separation of algae-bacteria biomass from water.

The results of BR test were positive in all samples except in HRAP and the results of BetaStar® combo test showed presence of ß-lactam antibiotics in all tested samples and a level of potential presence of desfuroylceftiofur (metabolite of antibiotic ceftiofur) in the outflow from WWTP and in HRAP. Based on positive results in our preliminary research (Prosenc et al., 2022) with three classes of chemicals (bisphenols, 2018 EU Watch List substances, pharmaceuticals) where we have proved that mixed algae-bacterial culture could remove most of spiked 28 CEC at environmentally relevant concentration (1–20 μg/L) and even outcompeting conventional activated sludge treatment, while others remained recalcitrant. Further analyses of CEC in HRAP biomass and WW will be performed with real concentrations. Therefore, we assume that the application of green products from algae-based systems in agriculture is possible regarding amended EU Regulation 2020/741 (EU Parliament, 2020), however, the ongoing research aims for providing clearer answers which substances need to be monitored on a regular basis in HRAP and other WWTP and how to manage microorganisms contamination in reclaimed water to minimise or avoid environmental and human health risk.

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References:

Bulc, T.G., Istenič, D., Klemenčič, A.K., 2011. The efficiency of a closed-loop chemical-free water treatment system for cyprinid fish farms. Ecol. Eng. 37. https://doi.org/10.1016/j.ecoleng.2011.01.004

Craggs, R., Park, J., Heubeck, S., Sutherland, D., 2014. High rate algal pond systems for low-energy wastewater treatment, nutrient recovery and energy production. New Zeal. J. Bot. 52, 60–73. https://doi.org/10.1080/0028825X.2013.861855

Craggs, R., Sutherland, D., Campbell, H., 2012. Hectare-scale demonstration of high rate algal ponds for enhanced wastewater treatment and biofuel production. J. Appl. Phycol. 24, 329–337. https://doi.org/10.1007/s10811-012-9810-8

European Commission, D.-G. for R. and I., 2015. Towards an EU research and innovation policy agenda for nature-based solutions & re-naturing cities: final report of the Horizon 2020 expert group on "Nature-based solutions and re-naturing cities" (full version). Publications Office of the European Union, Brussels.

Manyuchi, M.M., Mbohwa, C., Muzenda, E., 2018. Resource Recovery from Municipal Sewage Plants, 1st Editio. ed. CRC Press, Boca Raton. https://doi.org/https://doi.org/10.1201/9780429506239

Miralles-Wilhelm, F., 2021. Nature-based solutions in agriculture – Sustainable management and conservation of land, water, and biodiversity. FAO and The Nature Conservancy, Virginia. https://doi.org/https://doi.org/10.4060/cb3140en

Park, J.B.K., Craggs, R.J., 2011. Nutrient removal in wastewater treatment high rate algal ponds with carbon dioxide addition. Water Sci. Technol. 63, 1758–1764. https://doi.org/10.2166/wst.2011.114

Park, J.B.K., Craggs, R.J., Shilton, A.N., 2011. Wastewater treatment high rate algal ponds for biofuel production. Bioresour. Technol. 102, 35–42. https://doi.org/10.1016/j.biortech.2010.06.158

Parliament, E., 2020. Regulation (EU) 2020/741 of the European parlament and of the council of 25 May 2020 on minimum requirements for water reuse.

Prosenc, F., Piechocka, J., Škufca, D., Heath, E., Griessler Bulc, T., Istenič, D., Buttiglieri, G., 2021. Microalgae-based removal of contaminants of emerging concern: Mechanisms in Chlorella vulgaris and mixed algal-bacterial cultures. J. Hazard. Mater. 418, 126284. https://doi.org/10.1016/j.jhazmat.2021.126284

Renuka, N., Sood, A., Prasanna, R., Ahluwalia, A.S., 2015. Phycoremediation of wastewaters: a synergistic approach using microalgae for bioremediation and biomass generation. Int. J. Environ. Sci. Technol. 12, 1443–1460. https://doi.org/10.1007/s13762-014-0700-2

SHEER, 2018. Scientific Committee on Health, Environmental and Emerging Risks SCHEER Statement on Emerging Health and Environmental Issues (2018). https://doi.org/https://doi.org/10.2875/840266

Škufca, D., Kovačič, A., Griessler Bulc, T., Heath, E., 2021a. Determination of 18 bisphenols in aqueous and biomass phase of high rate algal ponds: Development, validation and application. Chemosphere 271, 129786. https://doi.org/10.1016/j.chemosphere.2021.129786

Škufca, D., Kovačič, A., Prosenc, F., Griessler Bulc, T., Heath, D., Heath, E., 2021b. Phycoremediation of municipal wastewater: Removal of nutrients and contaminants of emerging concern. Sci. Total Environ. 782, 146949. https://doi.org/10.1016/j.scitotenv.2021.146949

Solovchenko, A., Verschoor, A.M., Jablonowski, N.D., Nedbal, L., 2016. Phosphorus from wastewater to crops: An alternative path involving microalgae. Biotechnol. Adv. 34, 550–564. https://doi.org/https://doi.org/10.1016/j.biotechadv.2016.01.002

United Nations, 2015. The 17 Sustainable Development Goals, Sustainable Development.

Wang, Y., Guo, W., Yen, H.-W., Ho, S.-H., Lo, Y.-C., Cheng, C.-L., Ren, N., Chang, J.-S., 2015. Cultivation of Chlorella vulgaris JSC-6 with swine wastewater for simultaneous nutrient/COD removal and carbohydrate production. Bioresour. Technol. 198, 619–625. https://doi.org/https://doi.org/10.1016/j.biortech.2015.09.067

Tertiary wastewater treatment of anaerobic digestion effluents using a phytoremediation bioreactor

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Keywords (tertiary wastewater treatment, phytoremediation, *Lemna minor*, anaerobic digestion effluent)

ABSTRACT

Wastewater with high concentration of nutrients such as nitrogen, phosphorus and organic content generated from food industries or wastewater treatment plants constitutes a significant source of environmental degradation. The reduction of such substances in effluents is considered necessary for their safe disposal to the environment. Conventional wastewater treatments often encounter disadvantages due to unsuitable concentrations of pollutants and high levels of toxicity for their designed parameters, moreover issues regarding their sustainability of the wastewater treatment method are raised. Industrial activity in Greece constitutes a source of significant amounts of organic wastes. For instance, the quantity of wastewater produced due to the olive oil industry can be 0.6 to 2.0 m^3/ton of olive oil, meanwhile, the annual quantity of the olive oil industry in Greece accounts of around half a million cubic meters [1]. Phytoremediation is an emerging technology that uses plants in order to degrade or immobilize contaminants from soil and water. It is a cost effective technology that is usually applied to wastewater for reducing N and P to very low concentrations.

The main purpose of this study is the development of an ecological low cost phytoremediation wastewater treatment system of anaerobic digestion effluent that significantly reduces pollutants and produces high in protein plant biomass. The latter can be used as feed in the anaerobic digestion reactor for biogas production. The reduction of pollutants such as nitrogen and phosphorous in anaerobic digestion effluents was investigated in a lab scale continuous flow phytoremediation reactor containing the aquatic macrophyte *Lemna minor*. *Lemna minor* is a small free floating aquatic macrophyte that can occur worldwide, frequently developing mats on the surface of water bodies, such as lakes and low flow rivers. *Lemna minor* can achieve high biomass production rates and can accumulate nitrogen in its plant tissue up to 40% (dry base) [2]. It has been studied for its capability of removing pollutants, excess nutrients and other toxic substances from wastewater [3].

A continuous flow lab scale phytoremediation reactor with a volume of approximately 4 L (30cm*15cm*9cm) was applied, using the plant *Lemna minor* for wastewater treatment. At first, modified Hoagland nutrients solution was used as a feed to the reactor with a flow rate of 500 mL/day for plant cultivation. Subsequently, the flow rate of the nutrient solution was reduced while effluent wastewater from an anaerobic reactor and aerated for 3 days as a pre-treatment stage was gradually introduced to the continuous flow phytoremediation reactor with a final retention time of 7 days. The performance of the reactor was studied by focusing on certain parameters of the effluent before and after treatment. These parameters included pH, conductivity, alterations in the concentrations of ammonia nitrogen, phosphorus, Total Kjeldahl Nitrogen and Redfield ratio. Redfield ratio is the stoichiometric ratio of essential elements and in this case the Nitrogen-to-Phosphorus ratio in planktonic biomass and the ratio of inorganic nutrients existing in marine ecosystems. Its contribution in understanding the nutrient cycling and biological processes in aquatic ecosystems is of great importance [4].

The initial effluent from the anaerobic digester contained high concentrations of ammonia nitrogen with a value that varied between 150 to 250 mg of NH_4-N/L which was reduced by 98.4% after treatment. The phosphorus concentration which valued as high as 7 mg P/L was reduced by 82.9% and TKN was lowered by 97.8% with an initial concentration of up to 290 mg/L. The Redfield ratio was raised from an initial value

of 15.6 to 76.1 indicating that the nutrient limitation for microorganisms to grow shifts from nitrogen to phosphorous, concluding that the produced effluent does not favour eutrophication. The reactor had also produced excess plant biomass high in protein (up to 40%) and total organic carbon (33%) that had to be removed (about 1 g/L of fresh plant biomass weekly) in order for the phytoremediation process to continue functioning with a high performance.

The phytoremediation stage using a duckweed (*Lemna minor*) bioreactor proved to be significantly beneficial for the further detoxification of the anaerobic reactor's effluents as it manages to fairly improve the parameter of the resulting wastewater. Moreover, the production of plant biomass that occurs as a by-product of the process has a lot of potential to be used in agriculture, as animal feed or composting ingredient due to its high protein content or even as a feed in anaerobic digestion processes.

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References:

[1] Vlyssides, A.G., Lamprou, G.K., Vlysidis, A., 2017. Industrial case studies on the detoxificaton of OMWW using Fenton oxidation process followed by biological processes for energy and compost production, in: Olive Mill Waste: Recent Advances for Sustainable Management, Elsevier, Chapter 6, pp. 119–138.

[2] Iatrou E. I., Kora E., Stasinakis A. S., 2018. Investigation of biomass production , crude protein and starch content in laboratory wastewater treatment systems planted with Lemna minor and Lemna gibba. Environmental Technology, 2019, Vol. 20, 2649-2656

[3] Amare E., Kebede F., Mulat W., 2018. Wastewater treatment by Lemna minor and Azolla filiculoides in tropical semiarid regions of Ethiopia. Ecological Engineering 120 (2018) 464-473

[4] Clevelant C. C., Liptzin D., 2007. C:N:P stoichiometry in soil: is there a ''Redfield ratio'' for the microbial biomass? Biochemistry (2007) 85:235-252

Nitrogen fixation rate measurement by nitrogen fixing bacteria in a *Lemna minor* aquatic system

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Keywords: *Lemna minor*, nitrogen fixation, plant biomass, phosphorus consumption

ABSTRACT

Numerous studies have reported association of nitrogen fixing organisms and aquatic macrophytes [1]. Duckweed species from the subfamily *Lemnaceae* are a group of small free floating aquatic macrophytes that can grow worldwide, developing mats on the surface of water bodies, such as lakes and low flow rivers. They regularly display rapid growing rates, developing extensive mats on ponds and lakes, with usually symmetric, elliptic fronds solitary or connected in groups of mother-daughter fronds. *Lemna minor*, also known as common duckweed, under ideal conditions, can double its plant mass within a short time frame (usually two days) comprising a high protein content biomass (up to 40% dry base) [2]. Due to its fast biomass production and high protein content, *Lemna minor* accumulates large amounts of nutrients such as nitrogen and phosphorus, and for that reason, its capability of removing pollutants has been extensively studied in various wastewater treatment processes [3].

It has been observed that nitrogen fixation is a common occurrence during rapid growth of duckweeds in ponds and lakes. Studies have shown that duckweed can establish a symbiotic relationship with colonies of nitrogen fixing bacteria and cyanobacteria attached to the plant rhizosphere, in order to fulfil its high nitrogen uptake requirements. For duckweed communities, it has been reported that they promote the growth of blue-green algae over other types of algae [4]. The nitrogen fixation process during rapid duckweed growth has been confirmed by the acetylene reduction method. According to estimations, about 15 to 20% of the nitrogen required by duckweed can be acquired by biological nitrogen fixation from the atmosphere.

This study focuses on the nitrogen fixation kinetics during the cultivation of *Lemna minor* plants. A series of thirty batch aquatic plant growth reactors was carried out to determine the kinetics of nitrogen fixation process in the aquatic macrophytes system. Each reactor contained 45 mL of modified Hoagland nutrients solution and 30 *Lemna minor* plants at 25^{o}C with a photoperiod of 14 hours per day.

According to the experimental results, there was an initial period of adaptation of the plants that lasted approximately seven days and after that period the plant growth rate reached a positive value of 0.010 mg-biomass/d*mg-biomass. The maximum plant growth rate was equal to 0.067 mg-biomass/d*mg-biomass. During the adaptation period, the nitrogen transfer from the atmosphere to the plants was measured up to 0.33 mg-Nitrogen/mg-biomass*d. After the adaptation period, the nitrogen fixing rate was gradually decreased until the 8th day of the experiment reaching a negative value of -0.41 mg-Nitrogen/mg-biomass*d. Subsequently, the transfer rate increased again at 18th day of the experiment and reached a value of 1.20 mg Nitrogen/mg-biomass*d on day 40. The phosphorus content in the liquid phase remains almost constant during the adaptation period for about 20 days, after which the reduction rate rises up to 0.051 mg-P/mg-biomass*d on day 29. A similar reduction of total nitrogen in the liquid phase is observed during the same timeframe which equals to -0.989 mg N-nitrates/mg-biomass*d. The nitrogen in the plant biomass was reduced until day 21 after which, it started gaining nitrogen at a rate of up to 0,007 mg Nitrogen/mg-biomass*d. Ammonium nitrogen was not present in the liquid phase until the 33rd day which was equal to 1.69 mg NH_4-N/L. Nitrogen in ammonium form was kept in low concentrations until the end of the two months of cultivation, when it reached a concentration of 5.0 mg NH_4-N/L.

During the cultivation of *Lemna minor* in batch reactors, a significant alteration in the value of total nitrogen was observed which can be attributed to nitrogen fixation caused by nitrogen fixing bacteria that can grow in a symbiotic relationship with the plants. During the adaption period, total nitrogen was severely reduced in the culture, while later on the culture manages to acquire and raise its total nitrogen levels through nitrogen fixation. There is a crucial time frame during the cultivation (days 29-33) during which a large reduction in nitrates nitrogen and phosphorus occurs while ammonium nitrogen starts forming in the liquid phase.

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References:

[1] Zuberer D. A., 1981. Nitrogen Fixation (Acetylene Reduction) Associated with Duckweed (Lemnaceae) Mats. Applied and Environmental Microbiology, Apr. 1982, p. 823-828

[2] Iatrou E. I., Kora E., Stasinakis A. S., 2018. Investigation of biomass production , crude protein and starch content in laboratory wastewater treatment systems planted with Lemna minor and Lemna gibba. Environmental Technology, 2019, Vol. 20, 2649-2656

[3] Ozengin N., Elmaci A., 2007. Performance of Duckweed (Lemna minor L.) on different types of wastewater treatment., Journal of Environmental Biology, 2007, 28(2) 307-314

[4] Duong T. P., Tiedje J. M., 1985. Nitrogen fixation by naturally occuring duckweed-cyanobacteria associations., Canadian Journal of Microbiology, 2011, 31(4):327-330

Assessing Heavy Metal Pollution with Common Weeds: Unveiling their Bioindicator Potential

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ABSTRACT

Introduction

Heavy metals are a class of elements that are differentiated by their high density and atomic mass. They can be distinguished from lighter metals by their density, which is defined as being at least 5 g/cm^3 (Duffus, 2002; Koller and Saleh, 2018). When the density of these metals exceeds 5 g/cm^3, they are often referred to as being "silent killers" due to their toxic nature and ability to cause harm to living organisms and the environment (Orji et al., 2018). The sources of heavy metals can be divided into two main categories: natural sources and anthropogenic activities. Natural sources of heavy metals include weathering of the earth's crust, erosion, and other geologic processes (Dahyia et al., 2022). Anthropogenic activities, such as urban runoff, agriculture, and industrial processes, are also significant contributors to the presence of heavy metals in the environment (Morais et al., 2012; Jaishankar et al., 2014; Popoola et al., 2018). In fact, nearly all human activities have the potential to generate heavy metals as a byproduct. Moreover, heavy metals are known to have a persistent presence in the environment, as they are non-biodegradable (Ghori et al., 2019).

Therefore, monitoring and prevention of heavy metal pollution is one of the hot topics in environmental research. A novel strategy has been adopted to assess the health of ecosystems by utilizing certain living organisms as bioindicators (Malizia et al., 2012; Parmar et al., 2016). Biomonitoring is a systematic approach that utilizes living organisms to track environmental changes, serving diverse objectives such as assessing ecosystem health trends, understanding environmental impacts, and evaluating the effectiveness of interventions (Burger, 2006). By engaging organisms as bioindicators, biomonitoring bridges the gap between complex environmental dynamics and comprehensible insights, unveiling hidden narratives that might otherwise elude conventional observation methods. Biomonitoring provides a valuable method of analyzing the correlation between chemicals in the environment and their actual uptake by the body (Burger, 2006; Juberg et al., 2008; Cakaj et al., 2023), either positive or negative, and their subsequent effects on human society (Parmar et al., 2016). This study aimed to identify potential bioindicator species such as *Trifolium pratense*, *Alcea rosea*, and *Lolium multiflorum* var. Ponto that could effectively detect heavy metal contamination, particularly focusing on cadmium (Cd), lead (Pb), copper (Cu), and zinc (Zn) pollutants.

Materials and methods

The selected potential bioindicator species—*Trifolium pratense*, *Alcea rosea*, and *Lolium multiflorum* var. Ponto—underwent a rigorous evaluation under consistent soil conditions across three

distinct sites within Poznań city. These species were selected due to their prevalent occurrence across Europe.

To assess the capability of the selected plant species to accumulate Cd, Pb, Cu, and Zn, an experiment was meticulously designed. Moreover, the efficiency of phytoextraction of these heavy metals by the studied plants from the three research sites was evaluated using two parameters: bioconcentration and translocation. This comprehensive assessment except physiological responses such as dry mass, chlorophyl content, cell membrane stability (CMS), relative water content (RWC), dry mass, it also included a microscopic validation of leaf injuries, utilization of Evans blue staining, and the application of advanced image processing techniques to accurately measure necrotic leaf areas. The spectral wavelengths, spanning from 400 nm to 2500 nm, were employed to capture the overall health of the plants. Additionally, the widely accepted Normalized Difference Vegetation Index (NDVI) was utilized to quantify the extent of injuries caused by exposure to heavy metals.

Results

The results underscored the remarkable heavy metal accumulation potential of all the studied species. Notably, the bioconcentration factors (BCF) surpassed a value of 1 for both Zn and Cd across all plant species. Among them, *Alcea rosea* and *Lolium multiflorum*, showed high Zn accumulation with BCF values of 6.62 and 4.70, respectively. *Alcea rosea* also exhibited significant Cd accumulation with a BCF value of 8.51. *Trifolium pratense* displayed efficient translocation of Cu and Zn (TF_{Cu}=2.55, TF_{Zn}=2.67) as well as effective Cd translocation (TF_{Cd}=1.97). Moreover, a noticeable correlation came to light between anatomical leaf injuries and a decline in vegetation conditions, as quantified by the Normalized Difference Vegetation Index (NDVI).

Conclusion

In conclusion, the studied weed species have strongly established their role as reliable bioindicators for accurately assessing heavy metal contamination. Their consistent ability to accumulate heavy metals, as evidenced by bioconcentration factors consistently exceeding 1 for Zn and Cd across all species, underscores their effectiveness. Notably, *Alcea rosea* and *Lolium multiflorum* exhibited substantial Zn accumulation with BCF values of 6.62 and 4.70 respectively, while Alcea rosea displayed significant Cd accumulation with a BCF value of 8.51. Trifolium pratense demonstrated efficient translocation of Cu and Zn (TF_{Cu}=2.55, TF_{Zn}=2.67) and effective Cd translocation (TF_{Cd}=1.97).

Furthermore, a clear correlation emerged between leaf injuries and declining vegetation health, quantified through the Normalized Difference Vegetation Index (NDVI). Collectively, these results underscore the reliability of these bioindicator species for pinpointing heavy metal contamination. Their distinct characteristics and responses offer vital insights into the complex interplay between pollution and plant well-being, crucial for shaping effective environmental management strategies.

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References:

Burger, J., Gochfeld, M., Kosson, D. S., & Powers, C. W. (2006). Biomonitoring for ecosystem and human health protection at Amchitka Island. *Piscataway, NJ: CRESP*.

Dahiya, V. (2022). Heavy metal toxicity of drinking water: A silent killer. *GSC Biological and Pharmaceutical Sciences*, *19*(1), 020-025.

Duffus, J. H. (2002). " Heavy metals" a meaningless term? (IUPAC Technical Report). *Pure and applied chemistry*, *74*(5), 793-807.

Ghori, N. H., Ghori, T., Hayat, M. Q., Imadi, S. R., Gul, A., Altay, V., & Ozturk, M. (2019). Heavy metal stress and responses in plants. *International journal of environmental science and technology*, *16*, 1807-1828.

Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B. B., & Beeregowda, K. N. (2014). Toxicity, mechanism and health effects of some heavy metals. *Interdisciplinary toxicology*, *7*(2), 60.

Juberg, D. R., Bus, J., & Katz, D. S. (2008). *The opportunities and limitations of biomonitoring*. Mackinac Center for Public Policy.

Koller, M., & Saleh, H. M. (2018). Introductory chapter: Introducing heavy metals. *Heavy metals*, *1*, 3-11.

Malizia, D., Giuliano, A., Ortaggi, G., & Masotti, A. (2012). Common plants as alternative analytical tools to monitor heavy metals in soil. *Chemistry Central Journal*, *6*, 1-10, https://doi.org/10.1186/1752-153X-6-S2-S6

Morais, S., Costa, F. G., & Pereira, M. D. L. (2012). Heavy metals and human health. *Environmental health–emerging issues and practice*, *10*(1), 227-245.

Orji, O. A., Edosa, I. V. O., Ogbemudia, I., Omokaro, S. O., & Elenwo, C. E. (2018). Assesement of Some Heavy Metals in Soils and Plants Growth in Dumpsites. *IOSR J. of Environ. Sci., Toxi. and Food Tech*, *12*(3), 17-23.

Parmar, T. K., Rawtani, D., & Agrawal, Y. K. (2016). Bioindicators: the natural indicator of environmental pollution. *Frontiers in life science*, *9*(2), 110-118.

Pilz, D. (2006). *Broadening participation in biological monitoring: handbook for scientists and managers* (Vol. 680). US Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Popoola, L. T., Adebanjo, S. A., & Adeoye, B. K. (2018). Assessment of atmospheric particulate matter and heavy metals: a critical review. *International Journal of Environmental Science and Technology*, *15*, 935-948.

Study on algae composition of a river entering Taihu Lake and effect of constructed wetland on algae removal

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Keywords : Vertical flow constructed wetland; Algae composition; Algae removal ; Taihu lake

ABSTRACT

In order to study the effect of vertical flow constructed wetland (VFCW)on algae removal in the period of algae bloom in Taihu Lake, VFCW was constructed at the riparian area of Xiaoxia River, a river enteringTaihu Lake. The algae compositions of four sampling sites were detected in three batches and analyzed and the effect of VFCW on algae removal was studied. The results showed that the density and biomass of algae at different sampling sites of three batches were quite different, and there was no obvious proportional relationship between the cell density and biomass of algae at the same sampling site of the same batch; There are 6 phyla of algae in the three batches, involving 92 species, among which the dominant species are *Chlorophyta* (35 species), while the least species are *Pyrrophyta* (2 species); The cell density of three batches was dominated by *Cyanophyta*, and the algae were mainly *Planktolyngbya subtilis*, *Microcystis sp.*, *Merismopedia minima*. The algae removal rates of the three batches of VFCW were 70.09%, 90.18% and 99.94% respectively. The average removal rates of different phyla were all above 82%. The algal density and biomass of VFCW effluent were far lower than those of other sampling sites, indicating that VFCW had a good efficiency of algae removal when treating algae-laden water from Xiaoxia River of Taihu Ecological Island.

1 Introduction

Taihu Lake is located in the Yangtze River Delta region, which plays an important role in the local development and economy. However, since 1990s, the concentration of nitrogen and phosphorus in the water body has seriously exceeded Chinese standard (Xi Z., et al., 2020; Xi Z., et al., 2019). Although water quality of Taihu Lake has been improved, a lot of manpower and resources were invested deal with algae every year (Xi Z., et al., 2020; Xi Z., et al., 2019). In order to remove algae ecologically, a study on algae composition of Xiaoxia River entering Taihu Lake, and algae removal efficiency of VFCW were carried out.

2 Method

2.1 Site and sampling

The study was carried out at west island in Taihu Lake, Suzhou, Jiangsu, China. Both ends of the Xiaoxia River are connected to Taihu Lake, which directly affects the water quality of Taihu Lake. VFCW was built at the riparian area of Xiaoxia River, near the lake inlet. VFCW system is divided into two cells, with area 2000m^2 of each. Samples no.1, no.3 and no.4 are water from Xiaoxia River. In this study, three batches of samples were taken.

Table 1 Three batches of algae sampling information

Sampling batch	Volume	Date	Sampling batch	Sampling sites and number
The first batch	1 L	2022.08.09	2 p.m.	no.1: influent of VFCW no.2: effluent of VFCW no.3: north of Xiaoxia River no.4: south of Xiaoxia River
The second batch	1 L	2022.08.16	2 p.m.	
The third batch	1 L	2022.09.02	2 p.m.	

Samples from 4 sampling sites were stored in the same container for each sample of 1L. Immediately after sampling, 10-15ml of Lugo's iodine solution was added to the sample to fix. On the same day of sampling, the samples were sent to a professional algae testing laboratory for concentration and sedimentation treatment. Data such as algae density, algae biomass and algae species were tested.

2.2 Algae counting method

The instrument used is the biological microscope CX23, which is carried out according to the Technical Regulations for Phytoplankton Monitoring in Inland Waters (SL733-2016).

(1) Analysis of phytoplankton

The samples were made into specimen plates, and the morphological and structural characteristics of phytoplankton were observed with a microscope. The dominant species were identified as species, and the rest were identified as genus.

(2) Phytoplankton density

The number (density) of phytoplankton in a 1L water sample can be calculated by the formula:

When there is less than one phytoplankton per visual field, $N = 10P_nV_1$;

When the average number of phytoplankton per visual field is 1 to 2, $N = \frac{N_0}{N_1} \times \frac{V_1}{V_0} \times P_n$;

When the average number of phytoplankton per visual field is 3 to 50, $N = \frac{C_s}{F_s} \times \frac{P_n}{F_n} \times \frac{V_1}{V_0}$;

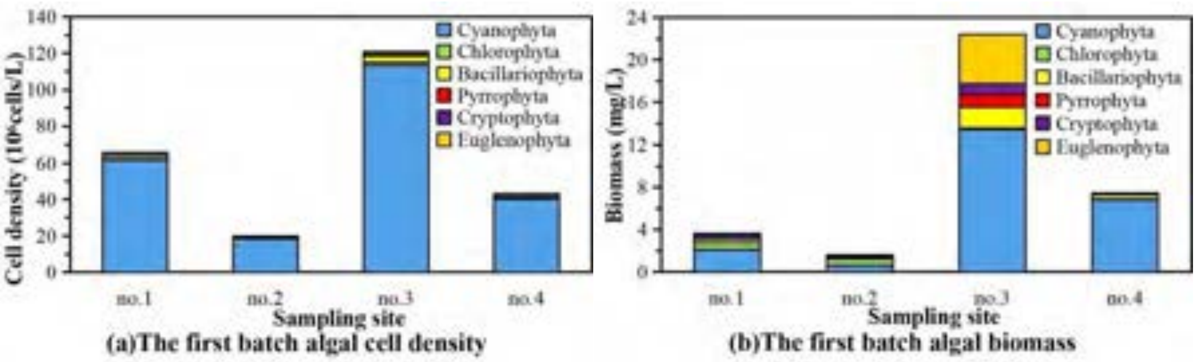
Where, N is the number of plankton in 1L water sample, cells/L; N_0 is the total number of counting squares in counting frame; N_1 is the number of counted squares; V_1 is the volume of 1L water sample after concentration, ml; V_0 is the volume of the counting frame; P_n is the number of counted phytoplankton; C_s is Area of counting frame, mm^2; F_s is field of view area, mm^2; F_s the number of fields of view counted per piece.

(3) Phytoplankton biomass

Phytoplankton biomass is measured by using volume measurements, which are then converted to biomass. When measuring, the length, height, diameter, etc. of phytoplankton are measured on the basis of its body shape, and then the average value is obtained, and the volume is calculated according to the quadrature formula.

3 Result and analysis

3.1 Algae composition at different sampling sites in three batches



(a)The first batch algal cell density (b)The first batch algal biomass

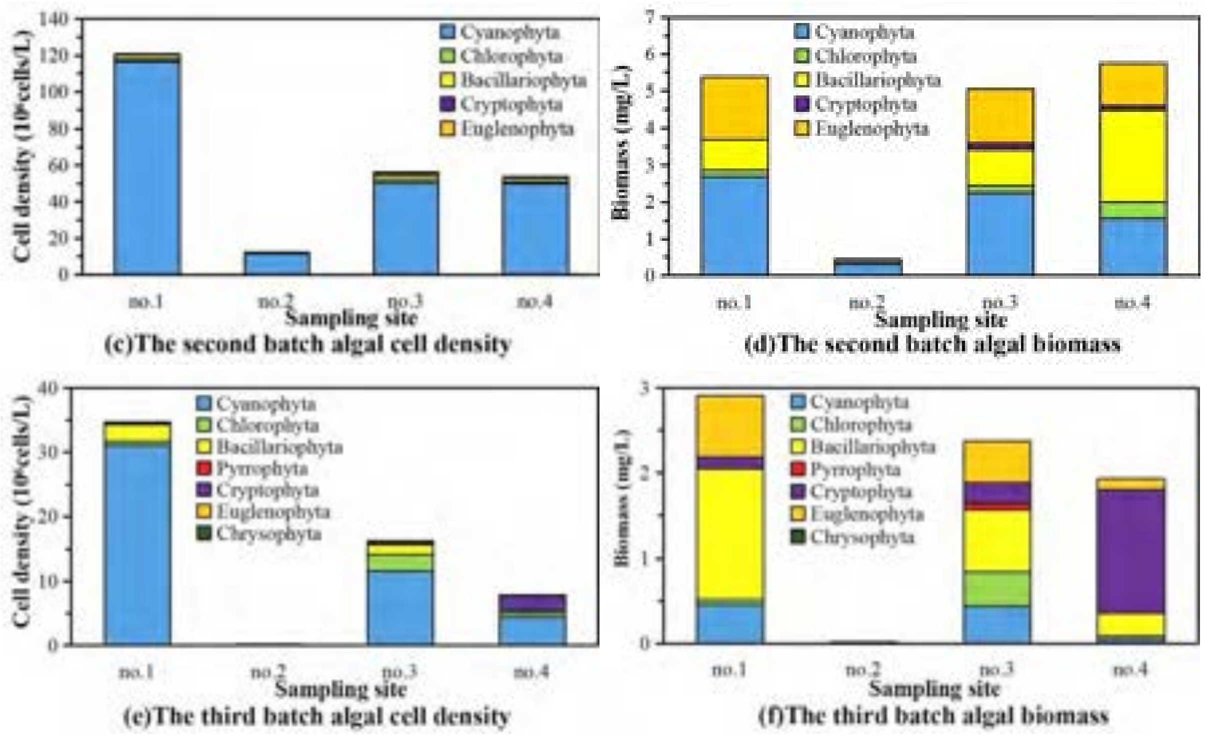


Figure 1. Algal composition of three batches and different sampling sites

On the whole, the results showed there was no obvious proportional relationship between the cell density and biomass of algae at the same sampling site of the same batch. From **Figure 1**(a)(c)(e), the order of magnitude of *Cyanophyta* in different batches of different sampling sites accounted for more than 72%, which is the main algae in Xiaoxia River. From **Figure 1**(b)(d)(f), the larger algae in *Euglenophyta* and *Bacillariophyta* could make full use of their advantages of high resource utilization rate, and although they do not occupy a large proportion in the order of magnitude, they have greater advantages in biomass.

3.2 Proportion of different algae species

Cell density and biomass of the same species of algae in the three batches of algae tests were accumulated respectively, and their proportions in the phyla were calculated.

Table 2. Algal cell density and biomass accounted for the top five algal species

Phylum	The top five main species of cell density and their proportion	The top five main species of biomass and their proportion
Cyanophyta **(16 species in total)**	*Planktolyngbya subtilis*(22%), *Microcystis sp.*(21%), *Merismopedia minima*(14%), *Pseudanabaena sp.*(13%), *Aphanocapsa delicatissima*(9%)	*Oscillatoria princeps*(49%), *Microcystis sp.*(23%), *Raphidiopsis sp.*(6%), *Cylindrospermopsis raciborskii*(6%), *Pseudanabaena sp.*(5%)
Chlorophyta **(35 species in total)**	*Scenedesmus bijuga*(12%), *Coelastrum*(10%), *Scenedesmus quadricauda*(10%), *Pandorina morum*(9%), *Actinastrum hantzschii*(8%)	*Chlamydomonas*(22%), *Mougeotia sp.*(13%), *Pandorina morum*(12%), *Spondylosium sp.*(7%), *Tetraedron trigonum*(5%)
Bacillariophyta **(23 species in total)**	*Cyclotella sp.*(66%), *Synedra acus*(17%), *Nitzschia*(6%), *Melosira granulata*(5%), *Navicula sp.*(2%)	*Cyclotella sp.*(60%), *Melosira granulata*(11%), *Synedra acus*(8%), *Gyrosigma attenuatu*(6%), *Nitzschia*(3%)
Pyrrophyta **(2 species in total)**	*Peridinium sp.*(87%), *Gymnodinium sp.*(13%)	*Peridinium sp.*(97%), *Gymnodinium sp.*(3%)
Cryptophyta **(7 species in total)**	*Cryptomonas sp.*(61%), *Chroomonas acuta*(14%), *Chroomonas placoidea*(13%), *Cryptomonas ovata*(4%), *Campylomonas reflexa*(4%)	*Cryptomonas sp.*(66%), *Campylomonas reflexa*(18%), *Cryptomonas ovata*(10%), *Chroomonas placoidea*(2%), *Chroomonas acuta*(1%)
Euglenophyta **(9 species in total)**	*Euglena sp.*(93%), *Strombomonas sp.*(2%), *Trachelomonas sp.*(2%), *Euglena acus*(1%), *Phacus bacillformis*(1%)	*Euglena sp.*(94%), *Strombomonas sp.*(2%), *Astasia sp.*(1%), *Trachelomonas sp.*(1%), *Euglena acus*(1%)

The results of the identification of algae showed that 92 species of algae were detected in three batches, involving 6 phyla. Among them, *Chlorophyta* has the most species (35 species), and *Pyrrophyta* has the least species (2 species). The cell density and biomass of *Bacillariophyta* are concentrated in the top five species, while the species proportion of *Cyanophyta* is more equal. The cell density and biomass of *Cyclotella sp.* in *Bacillariophyta*., *Peridinium sp.* in *Pyrrophyta*, *Cryptomonas sp.* in *Cryptophyta* and *Euglena sp.* in *Euglenophyta* were above 60%.

3.3 Efficiency of VFCW for algae removal

Algae cell density of influent and effluent of VFCW was used to calculate the algae removal rate of different phyla, so as to show the algae removal efficiency of VFCW. No *Cryptophyta* were detected in both influent and effluent of the second batch of algae test. The results are shown in the **Figure 2**:

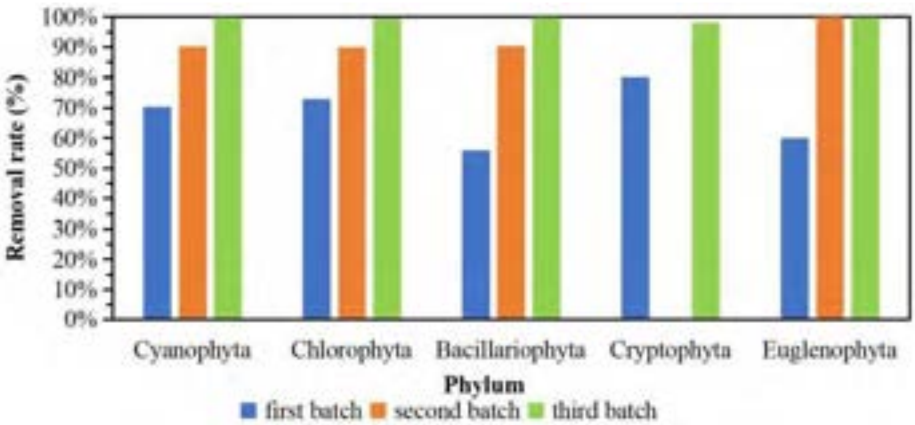


Figure 2. Removal rate of different algae in VFCW

As can be seen from **Figure 2**, the overall removal rates of algae in the first, second and third batches were 70.09%, 90.18% and 99.94%, respectively, increasing successively, with an average removal rate of 86.74%. For a single phylum, the average removal rate was close, among which removal rate of *Cryptophyta* (89.03%) was the highest and removal rate of *Bacillariophyta* (82.09%) was the lowest. In general, the removal rate of different phyla of algae in the three batches was more than 50%, and the removal rate of different algae in the third batch had reached more than 98%, indicating that the efficiency of algae removal in the third batch was the best.

The density of *Planktolyngbya subtilis* in *Cryptophyta* in influent of the second batch was the highest above 60×10^6 cells/L. There was no significant difference in the number of algae species in the effluent, but the cell density and biomass of algae were greatly reduced. In previous studies, the allelechemicals from wetland plants and the adsorption and interception of substrates and biofilm were important factors for the removal of algae (Jinlin C. et al., 2013; Haiyan F., et al., 2012).

4 Conclusion and prospect

The results show significant differences in algal density and biomass from three batches at different sampling sites. VFCW has a good removal ability for different algae in Xiaoxia River, which entering Taihu Lake. The further research will be done to study the removal efficiency of VFCW for algae in river water under different temperature conditions in different seasons, and the algae composition at different sites of Xiaoxia River connecting Taihu Lake. At the same time, in the case of different algae concentrations in the influent, the removal capacity range of VFCW will be explored in order to provide a basis for future project implementation.

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References:

Xi Z., Yun Z., 2019. Problems and countermeasures of controlling cyanobacteria bloom in Taihu Lake. Journal of Environmental Engineering Technology 9(6): 714-719, https://doi.org/10. 12153/j. issn. 1674-991X. 2019. 07. 080.

Xi Z., Guibao L., Shengrui W., 2020. Constructed Wetlands for industrial wastewater treatment. Water Resources Protection 36(6): 107-111, https://doi.org/10. 3880 /j.issn. 1004 — 6933. 2020. 06. 017.

Jinlin C., Xinxin S., Qing L., et al, 2013. Removal Effects of Constructed Wetlands on Algae. J.SHANXIAGRIC.UNIV(Natural Science Edition) 33(4): 319-323, https://doi.org/10.13842/j.cnki.issn1671-8151.2013.04.002.

Haiyan F., Ming H., Tian C., et al., 2012. Allelopathy Effects of Various Higher Landscape Plants on Chlorella pyrenoidosa. Advanced Materials Research, 518: 23-28, https://doi.org/10.4028/www.scientific.net/AMR.518-523.23

Session C7: Sustainability in practice

The SunAir Fountain panel: solar-powered drinking water production from the air humidity

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Keywords: constructed wetlands, aerated wetland, substrate media, wastewater treatment

ABSTRACT

The planet is composed of 70% water, but fresh water accounts for only 2.5% and less than 0.7% are accessible to humans. This meagre resource is also very unevenly distributed: 85% of the world's population lives in the driest part of the planet and 70% of water is used by agriculture, which can reach up to 90 per cent in developing countries. According to the United Nations, two billion people do not have access to safe drinking water. The United Nations' Sixth Sustainable Development Goal aims for universal and equitable access to safe drinking water, hygiene and sanitation, by 2030, especially for vulnerable populations. The UN goals will most probably not be achieved, in particular due to fast worsening climate conditions in a number of regions in the world. Therefore, there is a market for a solution; if it is an economical, ecological and practical alternative to the aforementioned challenges.

Agua de Sol SAS has developed the SunAir Fountain®, a solution for the production of drinking water using two abundant, renewable and free resources: atmospheric humidity and the sun.

The SunAir Fountain® works in two phases:

• At night, the drop in air temperature leads to the rise in the relative humidity, and water vapor is then trapped by the adsorbent.

• During the day, the solar energy releases the water vapor from the adsorbent, which is then cooled by the ambient air, and subsequently condensed.

Water is thus produced with ease and with reliability.

Key Advantages of the SunAir Fountain®:

- Sanitary: The tests and analysis carried out by laboratories approved by the French government, show that the water produced by SunAir Fountain® is quality drinking water.
- Ecological: Drinking water is produced and consumed locally. This is a 100% renewable water process. The ecological problem caused by plastic bottles is thus eliminated and the negative impact of transporting water bottles is also reduced. Finally, thanks to the use of solar energy, no electricity is taken from the grid, which further reduces the carbon footprint.
- Economical: The cost of producing locally a liter of water is much lower than that of purchasing bottled water.
- Practicality: The SunAir Fountain is easy to install and doesn't require any maintenance (air filter should be rinsed every 6 months and glass cleaned regularly, like any glass at home. The SunAir Fountain is scalable, from 1 panel to 2, 3, 4,…. up to tens, hundreds and thousands if required.

- Society: The SunAir Fountain provides a basic necessity: drinking water, which can improve the

situation for many families living in areas affected by water scarcity, like depleting ground water or polluted resources.

This study will present the first 6 prototype water panels that have been installed at the Technical University of Crete in order to further investigate the performance of the panels and identify ways to optimize the water production.

Session C8: Water reuse and sustainability

Utilizing treated wastewater for pasture irrigation: effects on productivity, plant community structure and soil properties

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Keywords: Herbage, Irrigation, Pasture, Productivity, Species richness, Wastewater

ABSTRACT

The proportion of wastewater reuse in Israel is the highest in the world. Irrigation with treated wastewater may impact pasture vegetation composition and herbage quality: the addition of water and nutrients to the soil may increase productivity and herbage quality. However, the addition of resources to the soil may change interplant interactions (competition level) in plant communities and gives an advantage to species with a high growth rate over small and drought-resistant species. This process can be accompanied by a decline in plant abundance and diversity. In addition, over time, irrigation with wastewater can reduce soil quality.

In order to test the effect of irrigation with treated wastewater on the vegetation and soil, ten grazing-prevention exclosures were established in the study site in Ramat-Hanadiv park, with half of them irrigated with treated wastewater. Irrigation was carried out for two years, only in the winter and in limited quantities; in weeks when it rained less than 50mm, irrigation filled the missing gap to reach 50mm. Every spring (in March), the vegetation composition, species richness, productivity, and various indices that express herbage quality and herbage nitrogen content, were sampled. The surveys were carried out during the two years of irrigation treatments and one year after the cessation of irrigation.

Irrigation with wastewater increased productivity by an average of 38% and total pasture protein production (biomass × %protein) by 9% relative to the control plots. At the same time, irrigation decreased plant protein values, while increasing herbage fibre content and lowering its digestibility. Our results showed that over two years species-richness and total plant abundance were reduced in the irrigated plots, and the abundance of small annual grasses and legumes declined. Most of the soil indices examined were not affected by irrigation, but in the vicinity of irrigation points, sodium values and SAR were higher than in areas without irrigation. Additional resources in winter enabled the plants to grow fast and high and increased interplant competition. The dominant plants in the irrigated plots were of fast-growing species; at the same time, small and drought-resistant species disappeared or declined in numbers due to competition for light. Changes in the vegetation composition were revealed in functional groups reshuffling and in species richness decline.

Conclusions: The results of our study show that wastewater irrigation caused an increase in productivity but a decrease in herbage quality. At the pastoral system level, the significant increase in productivity offsets the decrease in quality and leads to the addition of protein and herbage available to animals. Soil salinization may cause further changes in the vegetation in the long term and requires caution use of this tool.

Native vegetation for the reuse of treated municipal wastewater: Implications for greenhouse gas emissions

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Keywords: Land treatment, phytomanagement, climate change, nitrous oxide, carbon dioxide

ABSTRACT

In New Zealand (NZ), >90% of treated municipal wastewater (TMW) is currently discharged into the ocean and waterways (Water New Zealand, 2021). The input of TMW-associated plant nutrients can lead to eutrophication and toxic algal blooms in these environments (Jarvie et al., 2006). Furthermore, TMW discharge into waterbodies is offensive to Māori, the indigenous people of NZ (Morgan, 2006). The cultural health of waterbodies is impaired by the disposal of human waste such as TMW, independent of the treatment it received (Tipa & Teirney, 2006). Indigenous views on environmental management need to be respected under NZ legislation and government policy originating from the Treaty of Waitangi (Morgan, 2006). Application of TMW onto land is preferred as it utilises the inherent purifying potential thereof (Pauling & Ataria, 2010). However, human waste requires to be separated from food production, which makes the use of TMW for agricultural purposes undesirable (Ataria et al., 2016). Most land-applied TMW in NZ (46%) is released through high-rate discharge into wetlands and soakage trenches (Cass & Lowe, 2016). The rest of the TMW is applied to pasture (40%) or pine trees (12%), with the remaining 2% unknown (Cass & Lowe, 2016). Alternatively, the land application of TMW could be combined with ecological restoration through plantings of native vegetation (Meister et al., 2022).

Native vegetation may reduce nutrient losses from TMW land treatment systems compared to other species. Some plants in the Myrtaceae family (and others) distinctively affect the biogeochemical cycling of nitrogen (N) in soil (Esperschuetz et al., 2017; Franklin et al. 2017). Esperschuetz et al. (2017) reported lower levels of nitrate (NO_3^-) leaching under the NZ native species *Leptospermum scoparium* (mānuka) and *Kunzea robusta* (kānuka) compared to *Pinus radiata* (Monterey pine) following the addition of biowastes to soil. Similarly, Franklin et al. (2017) found that nitrous oxide (N_2O) emissions were lower from soil under *K. robusta*. These and other nutrient immobilising species might, therefore, reduce N losses from TMW land treatment systems more than exotic plantation forests. However, there is limited knowledge on the performance of many native species in TMW land treatment systems, as well as their effect on nutrient fluxes. In a long-term field trial on Banks Peninsula (NZ), we demonstrated that irrigation of TMW at 1000 mm yr^{-1} can accelerate native plant growth, although this effect differed between species (Meister et al., 2022). However, most of the applied N (194 kg N ha^{-1} yr^{-1}) could not be accounted for (Meister et al., 2022). Potential loss mechanisms are through NO_3^- leaching or gaseous N emissions (Robertson & Groffman, 2015). The latter could have significant implications for climate change, since N_2O is a potent greenhouse gas, with a global warming potential 298 times higher than that of carbon dioxide (CO_2) (Philibert et al., 2013).

To understand potential effects of the land application of TMW on climate change, we aimed to quantify the emission of greenhouse gases from TMW-irrigated NZ native vegetation. Furthermore, we sought to determine if greenhouse gas emissions are affected by plant species, as previously indicated for N_2O emissions under *K. robusta*.

This study was based at a long-term field trial on Banks Peninsula in NZ (43°45′ 9″S, 172°56′ 36′′E). The trial was established in July 2015. 11 perennial NZ native plant species were planted, divided into three vegetation types, with a total of 1350 seedlings. These were arranged in 24 plots of 5 m x 5 m, whereof half received TMW irrigation from the local wastewater treatment plant at 1000 mm yr^{-1} through surface drip irrigation. The other half were non-irrigated control plots. TMW irrigation was equivalent to a N application rate of 194 kg N ha^{-1} yr^{-1}. The soil at the site is a Pawson silt loam (46% sand, 29% silt, 25%

clay). In 2022, a static headspace chamber method was used to measure GHG emissions from underneath three species: *K. robusta*, *Coprosma robusta* (karamu), and *Cordyline australis* (cabbage tree). Two headspace collars (11cm high, 20 cm diameter) were installed in each plot near the base of the selected species. At the time of collar installation, soil samples were collected in close proximity (<0.3 m) of the collars. These were analysed for pH, electrical conductivity (EC), soil moisture, total carbon (C) and N, as well as NO_3^- and ammonium (NH_4^+). Water filled pore space (WFPS) was calculated based on soil bulk density determined by McIntyre (2018). Gas samples were collected from the collars on 10 occasions between December 2021 and March 2022. Upon each sampling event, background samples were collected from the chambers prior to closure. Lids fitted with rubber septa were used to create sealed chambers. Gas samples were consequently collected at t= 0, 60, and 120 minutes after closure using an air-tight glass syringe. Samples were collected in evacuated exetainers and later analysed for N_2O and methane (CH_4) by gas chromatography. Analytical results were used to calculate GHG fluxes from the soil. CH_4 was excluded from analysis due to 35% of samples having CH_4 concentrations below the detection limit (1.5 µL L^{-1}). A LI-COR LI-8100A instrument was used to measure CO_2 flux data *in-situ*. CO_2 fluxes were measured on seven occasions between December 2021 and March 2022.

Soil chemistry results showed that there was no difference in total soil C (4.5%) and N (0.43%), as well as NH_4^+ (4 mg kg^{-1}), NO_3^- (20 mg kg^{-1}) and pH (5.2) between the control and TMW-irrigated treatment. This is consistent with previous measurements at the site, whereby TMW irrigation had no effect on these variables in the topsoil (Meister et al., 2022). However, in this study, WFPS was significantly higher in the TMW-irrigated treatment (61 ± 3.7%) compared to the control treatment (48 ± 3.4%). Similarly, the EC was significantly higher in the TMW-irrigated treatment (120 ± 8.6 µS cm^{-1}) compared to the control treatment (93 ± 5.0 8.6 µS cm^{-1}). WFPS was positively correlated with N_2O emissions ($p<0.05$), indicating that denitrification was mainly controlled by soil moisture and oxygen concentration (Robertson & Groffman, 2015).

N_2O emissions from the TMW-irrigated soils were 573% higher than from the non-irrigated control when all species were combined (848 vs. 163 g N_2O-N ha^{-1} yr^{-1}). However, when looking at the individual species, the increase in N_2O emissions was only significant in *K. robusta*. N_2O emissions in *K. robusta* were 11 times higher in the TMW-irrigated soils (1475 g N_2O-N ha^{-1} yr^{-1}) compared to the control treatment (134 g N_2O-N ha^{-1} yr-^{1}). The N_2O emissions in the control treatment under *K. robusta* were up to two times higher than those reported from established *K. robusta* and *L. scoparium* scrubland (72 g N_2O-N ha^{-1} yr^{-1}, Hedley et al. (2013)) and from *K. robusta* (95 g N_2O-N ha^{-1} yr^{-1}, Franklin et al. (2017)). These differences may derive from different environmental conditions or sampling in different seasons. Our results were in contrast with previous studies, whereby *K. robusta* has the potential to suppress denitrification and reduce N_2O emissions more than other species (Esperschuetz et al., 2017; Franklin et al., 2017).

Expressing the percentage of applied N that is lost through N_2O emissions in the TMW-irrigated soil, the calculated emission factor for all species was 0.35%. The emission factor by species was 0.12% in *C. australis*, 0.25% in *C. robusta,* and 0.69% in *K. robusta*. With higher application rates of 500 kg N ha^{-1} yr^{-1}, a study by Clough et al. (2004) measured N_2O emissions from 2 to 8.5 kg N_2O-N ha^{-1} yr^{-1}, which is equivalent to an emission factor of 0.4-1.7%. Similarly, Ding et al. (2022) reported N_2O emissions of 5.2 kg ha^{-1} yr^{-1} following the addition of 400 kg N ha^{-1} yr^{-1}, which is equivalent to an emission factor of 1.3%. Both studies were conducted in similar soil types with comparable WFPS and pH values. The lower emission factor found in this study indicates that N_2O emissions are not directly proportional to N application rates. Additionally, it is likely that native vegetation has different effects on N fluxes compared to pasture used in previous studies. Such differences may derive from distinct root morphologies, root exudation, and plant uptake, for example (Fisk et al., 2015). Based on reported N_2O:(N_2O+N_2) product ratios from 0.041 to 0.91 (Bizimana et al., 2022; Ding et al., 2022; Weier et al., 1993), the total estimated gaseous N emissions (N_2O + N_2) at the site ranged from 0.46 to 44 kg N ha^{-1} yr^{-1}. Although highly variable, this demonstrates that total N emissions can be a major N flux in TMW land application systems.

In contrast to N_2O, CO_2 emissions did not differ significantly between the TMW-irrigated and control plots. There were also no significant differences between species. Overall, average CO_2 emissions were equivalent to 16 ± 0.54 t C ha^{-1} yr^{-1}. This is consistent with soil respiration in native plantings reported by other studies (Hedley et al., 2013; Trotter et al., 2004). It was evident that CO_2 fluxes varied considerably between sampling times, with a significant correlation ($p<0.001$) between CO_2 fluxes and soil temperature explaining this observation. In contrast to other studies (Ibrahim et al., 2022), the lack of difference in CO_2 emissions between the TMW-irrigated and control soils indicate that microbial activity in the soil was not stimulated by TMW irrigation. Consistent with CO_2 emissions, total C concentrations did not differ between the treatments. On average, C concentrations in the topsoil were 4.5%, which was an increase compared to 3.4 % in soil samples taken 3 years prior (Meister et al., 2022). These additional C inputs likely derived from plant litter and root exudates (Paterson, 2003). The observed increase in total soil C over time indicates that native vegetation has the potential to increase below-ground C stock, and this is likely unaffected by TMW irrigation. Given the previously reported growth benefit from TMW irrigation (Meister et al., 2022), it is possible that TMW irrigation will lead to an overall increase in C stocks in native plantings.

In conclusion, this study has demonstrated that N emissions are likely to contribute substantially to N losses from TMW-irrigated soil. Plant species had a significant effect on N_2O emissions, which indicates that species selection may be a critical tool to mitigate greenhouse gas emissions. Increased plant growth and plant uptake in the TMW-irrigated treatment may somewhat compensate for N losses and accelerate C sequestration. Future research should aim to establish a N mass balance model of TMW-irrigated native vegetation. Additionally, we are currently quantifying above- and below-ground C stocks in TMW-irrigated native vegetation. This will allow us to better understand the potential effect of using native vegetation in land treatment systems on C sequestration.

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References:

Ataria, J., Baker, V., Goven, J., Langer, E. R., Leckie, A., Ross, M., & Horswell, J. (2016). From Tapu to Noa - Māori cultural views on biowastes management: a focus on biosolids. http://www.cibr.org.nz/assets/Uploads/Newsletter-Thumb/CIBR-From-Tapu-to-Noa.pdf

Bengtsson, G., Bengtson, P., & Månsson, K. F. (2003). Gross nitrogen mineralization-, immobilization-, and nitrification rates as a function of soil C/N ratio and microbial activity. Soil Biology and Biochemistry, 35(1), 143-154. https://doi.org/10.1016/s0038-0717(02)00248-1

Bizimana, F., Luo, J., Timilsina, A., Dong, W., Gaudel, G., Ding, K., Qin, S., & Hu, C. (2022). Estimating field N2 emissions based on laboratory-quantified N2O/(N2O + N2) ratios and field-quantified N2O emissions. Journal of Soils and Sediments, 22(8), 2196-2208. https://doi.org/10.1007/s11368-022-03212-0

Cass, S., & Lowe, H. (2016, 16-18 March). How much municipal wastewater passes through land in New Zealand? NZ Land Treatment Collective Conference, Gisborne.

Clough, T. J., Kelliher, F. M., Sherlock, R. R., & Ford, C. D. (2004). Lime and soil moisture effects on nitrous oxide emissions from a urine patch. Soil Science Society of America Journal, 68(5), 1600-1609. https://doi.org/10.2136/sssaj2004.1600

Ding, K., Luo, J., Clough, T. J., Ledgard, S., Lindsey, S., & Di, H. J. (2022). In situ nitrous oxide and dinitrogen fluxes from a grazed pasture soil following cow urine application at two nitrogen rates. Science of The Total Environment, 838, 156473. https://doi.org/10.1016/j.scitotenv.2022.156473

Esperschuetz, J., Balaine, N., Clough, T., Bulman, S., Dickinson, N. M., Horswell, J., & Robinson, B. H. (2017). The potential of L. scoparium, K. robusta and P. radiata to mitigate N-losses in silvopastural systems. Environmental Pollution, 225, 12-19. https://doi.org/10.1016/j.envpol.2017.03.042

Fisk, L. M., Barton, L., Jones, D. L., Glanville, H. C., & Murphy, D. V. (2015). Root exudate carbon mitigates nitrogen loss in a semi-arid soil. Soil Biology and Biochemistry, 88, 380-389. https://doi.org/10.1016/j.soilbio.2015.06.011

Franklin, H. M., Woods, R. R., Robinson, B., & Dickinson, N. (2017). Nitrous oxide emissions following dairy shed effluent application beneath Kunzea robusta (Myrtaceae) trees. Ecological Engineering, 99, 473-478. https://doi.org/10.1016/j.ecoleng.2016.11.064

Hedley, C. B., Lambie, S. M., & Dando, J. L. (2013). Edaphic and environmental controls of soil respiration and related soil processes under two contrasting manuka and kanuka shrubland stands in North Island, New Zealand. Soil Research, 51(5), 390-405. https://doi.org/doi.org/10.1071/SR12248

Ibrahimi, K., Attia, K. B., Amami, R., Américo-Pinheiro, J. H. P., & Sher, F. (2022). Assessment of three decades treated wastewater impact on soil quality in semi-arid agroecosystem. Journal of the Saudi Society of Agricultural Sciences, 21(8), 525-535. https://doi.org/10.1016/j.jssas.2022.03.002

Jarvie, H. P., Neal, C., & Withers, P. J. A. (2006). Sewage-effluent phosphorus: A greater risk to river eutrophication than agricultural phosphorus? Science of The Total Environment, 360(1), 246-253. https://doi.org/10.1016/j.scitotenv.2005.08.038

McIntyre, C. (2018). The potential of treated municipal wastewater irrigation to cause aggregate instability and pore sealing on Banks Peninsula soils Lincoln University].

Meister, A., Li, F., Gutierrez-Gines, M. J., Dickinson, N., Gaw, S., Bourke, M., & Robinson, B. (2022). Interactions of treated municipal wastewater with native plant species. Ecological Engineering, 183, 106741. https://doi.org/10.1016/j.ecoleng.2022.106741

Morgan, T. K. K. B. (2004, 7-9 July). A Tangata Whenua Perspective on Sustainability using the Mauri Model. Towards decision making balance with regard to our social, economic, environmental and cultural well-being. International Conference on Sustainability Engineering and Science, Auckland, New Zealand.

Morgan, T. K. K. B. (2006). An indigenous perspective on water recycling. Desalination, 187(1-3), 127-136. https://doi.org/10.1016/j.desal.2005.04.073

Paterson, E. (2003). Importance of rhizodeposition in the coupling of plant and microbial productivity. European Journal of Soil Science, 54(4), 741-750. https://doi.org/10.1046/j.1351-0754.2003.0557.x

Pauling, C., & Ataria, J. (2010). Tiaki Para: A Study of Ngāi Tahu Values and Issues Regarding Waste (Landcare Research Science Series, Issue. M. W. Press.

Philibert, A., Loyce, C., & Makowski, D. (2013). Prediction of N2O emission from local information with Random Forest. Environmental Pollution, 177, 156-163. https://doi.org/10.1016/j.envpol.2013.02.019

Robertson, G. P., & Groffman, P. M. (2015). Nitrogen Transformations. In E. A. Paul (Ed.), Soil Microbiology, Ecology and Biochemistry (pp. 421-446). https://doi.org/10.1016/b978-0-12-415955-6.00014-1

Tipa, G., & Teirney, L. (2006). A cultural Health Index for Streams and Waterways: A tool for nationwide use.

Trotter, C. M., Tate, K. R., Saggar, S., Scott, N. A., & Sutherland, M. A. (2004). A multi-scale analysis of a national terrestrial carbon budget and the effects on land-use change. In M. Shiyomi (Ed.), Global Environmental Change in the Ocean and on Land (pp. 311-341). TERRAPUB.

Water New Zealand. (2021). Wastewater treatment plant inventory. Retrieved 27/08/2021 from https://www.waternz.org.nz/WWTPInventory

Weier, K. L., Doran, J. W., Power, J. F., & Walters, D. T. (1993). Denitrification and the Dinitrogen/Nitrous Oxide Ratio as Affected by Soil Water, Available Carbon, and Nitrate. Soil Science Society of America Journal, 57(1), 66-72. https://doi.org/10.2136/sssaj1993.03615995005700010013x

Over 80% water recovery from urban greywater using nanofilter membranes – A Swedish Case Study

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Keywords: Greywater; Source Separated Sanitation; Water Reuse

ABSTRACT

With the introduction of the EU urban water reuse directive in 2023 ((EU) 2020/741), the importance of water and resource recycling is front of mind. Source separation of greywater like in Oceanhamnen, a redeveloped city district in Helsingborg, Sweden is an example for how wastewater infrastructure could be developed in the future to make reuse easier. Oceanhamnen uses separation of toilet blackwater from greywater to allow for easier treatment and reuse of greywater as well as easier nutrient recovery and energy production from blackwater. Greywater is treated with a combination of biological and mechanical treatment at the treatment plant; RecoLab. It is first treated through a two-stage anaerobic-aerobic activated sludge system that includes settling followed by a drum filter and thereafter nanofiltration (400 Da). Membrane reject water is ozonated and recirculated for micropollutant removal. RecoLab has been in operation for two years and is currently treating 900 PE (50 m3/d) with a design capacity of 2500 PE. Since the start of operation, average removal of 78% of COD, 65% of total nitrogen (N-tot), and 45% of total phosphorus (P-tot) were achieved for greywater through biological treatment alone. Following biological treatment with a drum filter and nanofiltration increased these removal efficiencies to 98%, 84%, and 88% for COD, N-tot, and P-tot, respectively. These removals corresponded to consistent effluent residual concentrations below 10 mg/L COD, 2 mg/L N-tot, and 0.2 mg/L P-tot. Nanofiltration has already been used extensively in greywater treatment (Hyde et al., 2016) and its ability to remove micropollutants has recently been a center focus of nanofilter implementation (Rutten et al., 2023). Regarding reuse, the EU urban water reuse directive only stipulates that BOD_5 must be less than 10 mg/L regarding nutrients for reclamation class A, meaning that nanofilter permeate from RecoLab is suitable for all forms of non-potable reuse mentioned in the directive if microbial parameters are met. Even during sludge washout events from the biological treatment, COD, N-tot, and P-tot concentrations were still low after nanofiltration while spikes in concentrations were clearly seen during these disturbances at the effluent point of the sedimentation tank, indicating that nano filtration acts as a redundancy to biological treatment. Furthermore, there were no interruptions in the function of nanofiltration during these same events, indicating that the drum filter is adequate pretreatment to an NF process. The current operation configuration has >80% water recovery with the only waste stream coming from weekly chemical cleanings of the nanofilters. To further exploit water reuse potential, the greywater treatment line is implementing pathogen barriers in the coming years to achieve drinking water quality. As the first Nordic source separation pilot project of its scale, RecoLab offers a promising glimpse into the future of water recovery from wastewater.

References:

(EU) 2020/741. REGULATION (EU) 2020/741 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL Minimum Requirements for Water Reuse.

HYDE, K., SMITH, M. J. & ADEYEYE, K. 2016. Developments in the quality of treated greywater supplies for buildings, and associated user perception and acceptance. *International Journal of Low-Carbon Technologies,* 12, 136-140.

RUTTEN, S. B., LEVERING, V. L., HERNÁNDEZ LEAL, L., DE GROOTH, J. & ROESINK, H. D. W. 2023. Retention of micropollutants by polyelectrolyte multilayer based hollow fiber nanofiltration membranes under fouled conditions. *Journal of Water Process Engineering,* 53, 103760.

Integrating academic knowledge on "Sustainability of Agricultural Water Management"

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Keywords: Multidisciplinary, Co-production, experiential knowledge, Sustainability, Climate change.

ABSTRACT

Sustainability is of utmost importance in the agriculture sector. It is the largest consumer of freshwater, equaling 70% of total global water withdrawals (Rosegrant, Ringler, and Zhu., 2009). Agriculture runoff can cause severe harm to surface and subsurface water quality through excess nutrient and pesticide loadings (Mateo-Sagasta, Zadeh, and Turral, 2018). In the EU, agriculture consumes 28% of total water abstraction and is responsible for polluting 38% of water bodies (European Court of auditors, 2021). In addition, the EU has experienced severe drought over the decades, and water management is mainly focused on a crisis-oriented approach (Cammalleri et al., 2020). Taken together, they underscore the need for sustainable water use in agriculture.

Furthermore, the EU Water Framework Directive (WFD) establishes a legal framework to protect and restore clean water in the EU and ensure its long-term sustainable use (EU directive, 2019). Sustainability in agricultural water management is also directly linked with the United Nations' Agenda 2030 Sustainable Development Goals (SDG), in particular, SDG 6: Clean Water and Sanitation and also SDG 2: Zero Hunger, and SDG 13: Climate Action (Tsani, Koundouri, and Akinsete., 2020). Thus, to address the need and comply with the global and regional frameworks, there is a need to dissipate the knowledge on the sustainability of agricultural water management (SAWM).

However, the SAWM is a multidimensional way of thinking about the interrelationships among natural, social, and economic systems in water use at the local level (Flint 2004). This interrelationship makes sustainability an elusive concept that can lead to operational difficulties (Marshall and Toffel 2005; White 2013). Therefore, this research aims to build knowledge in the SAWM for its better understanding to help streamline agricultural and environmental policies to avoid poor practices and compliance. Considering sustainability as a complex and multifaceted concept, a deeper understanding of it requires knowledge from science and society utilizing the multidisciplinary approach (Scholz and Steiner 2015). Therefore, this study utilizes the concept of co-production of knowledge by applying a systematic literature review to provide the extent of studies and experiential knowledge to define sustainability in the context of a multidisciplinary project.

The extent of studies on SAWM was studied through a systematic literature review (SLR). A SLR (for the period 1970-2021) was conducted by considering the keywords "*Pathways AND sustainable AND water AND management AND agriculture* AND (LIMIT-TO (LANGUAGE, "English"))."* The search was further converged through three steps: first, by considering the three pillars of sustainability, namely social, economic, and environmental, and their permutations; second, by considering the literature from the EU region; and third, by considering peer-reviewed journals and conference proceedings.

The results (Figure 30 General overview of the literature based on temporal, spatial and keywords variability (not in scale)) showed an exponential rise in literature with an average annual increase of 25% and a rapid increase in numbers after the Rio Conference 1992. Among the published 34536 articles during this period, most were related to environmental sustainability. The spatial analysis of the literature showed that there was a representation of at least one article from each country, with the majority from the United States,

followed by China, the United Kingdom, and Germany. It is worth considering that the EU countries collectively had a high publication rate. China's presence in this field has been increasingly significant since the early 2000s. Among the countries in the Global South, only India has earned a spot in the top ten based on the number of articles published. When analyzing the representation of sustainability pillars in published articles, it's clear that there's a notable discrepancy in the number of articles focused on environmental sustainability versus economic and social sustainability. Environmental sustainability is represented in more articles than economic and social sustainability, which follow in fewer numbers. This disparity in the article can be observed when analyzing the data over different temporal and spatial scales.

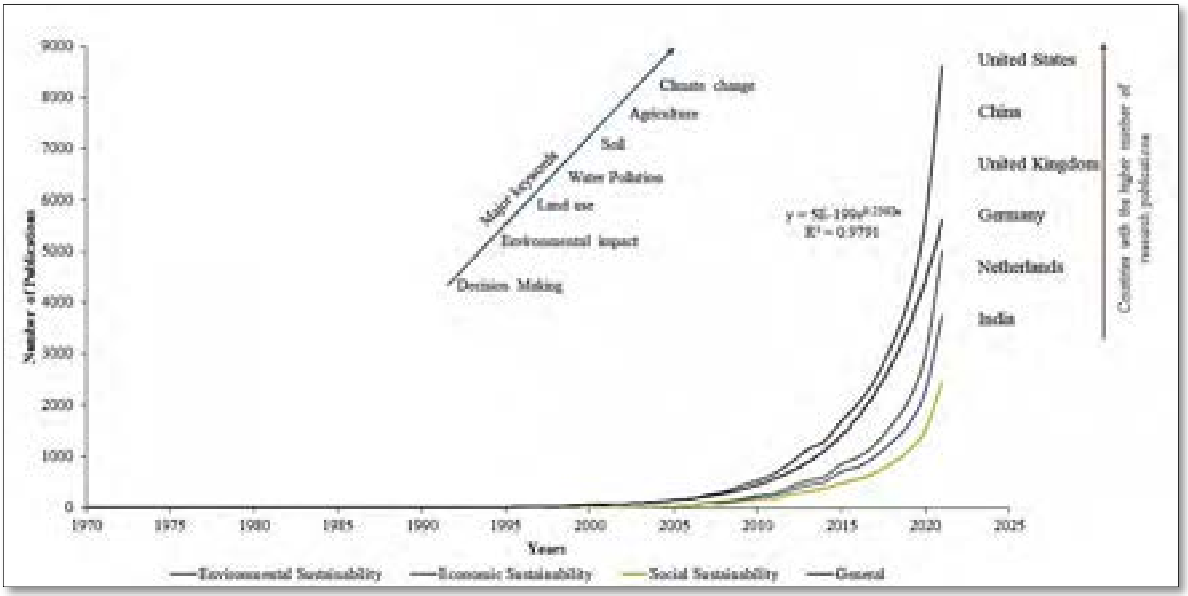

Figure 30 General overview of the literature based on temporal, spatial and keywords variability (not in scale)

The analysis of major keywords shows that 'climate change' is the most repetitive keyword in the research topic in general and in all sustainability themes. 'Agriculture' is the second most used keyword, followed by 'soil' and 'water pollution'. The analysis of keywords in each decade indicates 'phosphorous' as the most important keyword before 2000, which was later replaced by 'environmental protection' in the first decade of 2000. After 2010, 'climate change' significantly plunged into the keywords now highly considered in the literature. Furthermore, the literature review showed that defining sustainability in agriculture water management is highly contextual and mainly focuses on practices and technologies adopted.

After reviewing the literature on "sustainability," a Delphi survey was conducted to capture the experiential knowledge of experts. The aim was to utilize this knowledge to establish a clear definition of "Sustainability" in the context of water management in agriculture. "*The Delphi survey is a structured communication technique based on a panel of experts; it differs from the usual survey as it is an iterative process of questions and answers*" (Hugé et al. 2010). The views of twenty-nine experts representing the consortium members and stakeholders of a multidisciplinary European Horizon 2020 project (WATERAGRI) and others from different countries in the Global South were considered for the study. The result showed that most experts were more inclined towards the environmental pillars of sustainability rather than its social or economic dimension. The frequently mentioned concepts (**Error! Reference source not found.**) related to sustainable water management were collected by considering the responses, among which 'climate change' was considered the most important concern by all groups of respondents. However, there were also differences between the views of different groups of experts. Experts from the EU were more concerned about 'water quality', 'well-being', and 'economic growth', while those from the Global South mentioned more often 'water quantity', 'inclusive governance', and 'income generation'. There were also differences in views between consortium members and stakeholders in the same project. Consortium members were more concerned about 'nutrient runoff and water pollution', 'effective laws and regulations', and 'economically efficient technologies', whereas those representing stakeholders focused on 'changes in agricultural practices,' 'capacity building,' and 'subsidies and incentives'. The survey results also revealed gender differences in the perceptions of sustainable water management. Female experts emphasized 'water availability', 'stakeholder participation', 'co-decision making', and 'income and affordability' more often than male experts.

Table 16 Key concepts obtained from various groups of experts

Experts from global North	Experts from the global South	Consortium members	Stakeholders	Female experts
		Climate change		
• Water quality • Well-being • Economic growth • Climate change	• Water quantity • Inclusive governance • Income generation • Climate change	• Nutrient runoffs and water pollution • Effective laws and regulations • Economically efficient technologies • Climate change	• Changes in agriculture practices • Capacity buildings • Subsidies and incentives • Climate change	• Water availability • Stakeholder participation • Co-decision making • Income and affordability • Climate change

These varying perceptions were brought together to create a common definition. Based on the identified key concepts, SAWM is defined as follows:

"Managing water in a way that ensures its quality and has minimal negative effects on the natural environment. It involves stakeholder satisfaction and well-being, ensuring equal participation, and improving competency by entailing effective governance and equitable laws. It promotes long-term economic growth and provisions of incentives and subsidies. In summary, it exemplifies the ideal level of water management incorporating climate change concerns."

This definition forms the basis for WATERAGRI and can be used in similar multidisciplinary project settings.

SAWM is a complex and contextual issue that requires knowledge integration from a wide variety of sources. The Delphi survey in this study brings the opinion of experts in identifying the key concepts in all three pillars of sustainability, whereas the SLR provided the overview of existing literature on the subject matter. The definition of sustainability eases communication among practitioners in multidisciplinary projects. This helps in overcoming operational difficulties. The findings of the Delphi survey resembled the output of the SLR: in both cases the environmental pillar of sustainability was in focus. Furthermore, the frequently mentioned key concepts in both cases were similar. Therefore, integrating these two methods constitutes a multidisciplinary approach that provides a more holistic understanding of sustainable water management. This allows decision-makers to better understand sustainable water management's challenges and opportunities and prioritize their efforts accordingly. This integration of knowledge can also facilitate the development of evidence-based policies and practices for sustainable water management. It also helps promote collaboration between researchers and practitioners in the field which collectively generate new ideas.

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References

Cammalleri, C., G. Naumann, L. Mentaschi, G. Formetta, G. Forzieri, S. Gosling, B. Bisselink, A. De Roo, and L. Feyen. 2020. "Global Warming and Drought Impacts in the EU." *Publications Office of the European Union: Luxembourg*.

Directive, EU Water Framework. 2019. "Introduction to the EU Water Framework Directive." *European Commission, Environment. Np, Nd Web* 8.

Flint, R. Warren. 2004. "The Sustainable Development of Water Resources." *Water Resources Update* 127: 48–59.

Gatto, Marino. 1995. *Sustainability: Is It a Well Defined Concept?* JSTOR.

Grizzetti, Bruna, Olga Vigiak, Angel Udias, Alberto Aloe, Michela Zanni, Faycal Bouraoui, Alberto Pistocchi, Chiara Dorati, Rene Friedland, and Ad De Roo. 2021. "How EU Policies Could Reduce Nutrient Pollution in European Inland and Coastal Waters." *Global Environmental Change* 69: 102281.

Hugé, Jean, Hai Le Trinh, Pham Hoang Hai, Jan Kuilman, and Luc Hens. 2010. "Sustainability Indicators for Clean Development Mechanism Projects in Vietnam." *Environment, Development and Sustainability* 12 (4): 561–71.

Marshall, Julian D., and Michael W. Toffel. 2005. "Framing the Elusive Concept of Sustainability: A Sustainability Hierarchy." *Environmental Science & Technology* 39 (3): 673–82.

Mateo-Sagasta, Javier, S. Marjani Zadeh, and Hugh Turral. 2018. "More People, More Food, Worse Water?: A Global Review of Water Pollution from Agriculture."

Rosegrant, Mark W., Claudia Ringler, and Tingju Zhu. 2009. "Water for Agriculture: Maintaining Food Security under Growing Scarcity." *Annual Review of Environment and Resources* 34: 205–22.

Scholz, Roland W., and Gerald Steiner. 2015. "The Real Type and Ideal Type of Transdisciplinary Processes: Part II—What Constraints and Obstacles Do We Meet in Practice?" *Sustainability Science* 10 (4): 653–71.

Scoones, Ian. 2017. *Free-Book: Pathways To Sustainable Agriculture*. Routledge.

"SR_CAP-and-Water_EN.Pdf." n.d. Accessed September 27, 2022. https://www.eca.europa.eu/Lists/ECADocuments/SR21_20/SR_CAP-and-water_EN.pdf.

Tsani, Stella, Phoebe Koundouri, and Ebun Akinsete. 2020. "Resource Management and Sustainable Development: A Review of the European Water Policies in Accordance with the United Nations' Sustainable Development Goals." *Environmental Science & Policy* 114: 570–79.

Water, U. N. 2018. "Water in the 2030 Agenda for Sustainable Development."

White, Mark A. 2013. "Sustainability: I Know It When I See It." *Ecological Economics* 86: 213–17.

Poster Presentations

Survival rate of selected newly planted urban trees in the city of Nitra (Slovakia) in the context of circular economy

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Keywords: invasive species, tree care, arboriculture, urban forestry, insect pest damage, circular economy

ABSTRACT

Planting of urban trees is a perfect example of a circular economy, as the tree provides multiple benefits during its life, and can be used to manufacture products when it is cut down. Removal of a plantation tree results in space left for new tree planting, bringing employment to urban areas. The aim of this contribution is to evaluate the survival rate of newly planted urban trees in the city of Nitra (Slovakia) in the period 2016-2022. We selected to model species Celtis australis L. and Sorbus aria (L.) Crantz. The first mentioned species is a relatively new urban tree in Slovakia in the first plantings occurred in 2019 in the city of Nitra. In total 265 specimens were planted. The saplings were select standard sized (3 m height, 10-12 cm girth). The mortality was 23 %. Celtis australis is relatively pest free and the mortality was caused mostly by frost damage directly after planting (in the 1st year of growth). Also we observed better survival rate of trees in areas with perennial plantings, where the trees had a larger amount of water due to more frequent irrigation. When it comes to Sorbus aria it is a traditional urban tree used in the city of Nitra. The peak of the plantings were in the 90´s, but the fire blight radically decreased the number of adult trees. Since 2016 only 34 specimens were planted and the mortality was 78 %. The observed specimens died in the second year after planting and in the wood we observed Scolytus rugulosus, which attacks trees with low vitality caused by extreme heatwaves during summer. Sorbus aria is no longer a good choice urban tree in the conditions of Nitra, on the other hand planting of Mediterranean species like Celtis australis, which are more tolerant to heatwaves and water scarcity in urban soils can be a good decision. Our results clearly show that if municipalities want to have healthy and functional urban trees, they must start with planting the right species on the right place. Also tree care after planting is the next very important step. Translated in to economical terms wrong tree selection, planting and bad tree care is not cost effective. Alarming was the presence and abundance of Metcalfa pruinosa and the first record of Corythuca arcuata in the city park of Nitra in 2020. These new pests can be a vector for numerous plant pathogens. In conclusion urban trees in Nitra reduce harmful pollutants and mitigate summer air temperatures and they have both physical and mental health benefits for residents. Moreover urban trees provide numerous economic benefits. By selecting the right species, the city can save a lot of money, because trees can increase the economic revenue for retail shops, prevent unnecessary costs of road maintenance, and increase property values.

Reclamation of land from fluid hydrocarbon extraction: State of the art and current challenges

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Keywords: Reclamation, Oil production, Oil sands, Mining reclamation

ABSTRACT

Today, there is much discussion about the continued use of former mining sites, both underground and open pit (Raj K. Shrestha and Rattan Lal 2011; Yu Feng et al. 2019). There are different approaches to make these former industrial sites accessible to the public and nature, and to use the specific characteristics of the sites, for example for biotopes. For the oil and gas industry, such plans are not yet common because the storage sites are usually still in operation and the reuse and reclamation of federal lands is not necessarily as complex as in the case of surface mining.

To understand the potential reuse of these sites, it is important to consider the different methods used to extract oil and gas. While oil can be found both near the surface and in deeper formations, gas, due to the diffusion and volatility of its components, is mostly trapped in deeper geologic reservoirs that can only be accessed by unconventional methods. Oil can also be found in deep anticlines and oil sands, such as those found in Canada. It is important to consider the extent of surface use and proximity to surrounding areas during the extraction process when reclaiming used land.

In the case of deep wells and the use of an anticlinal structure, the amount of land reclamation required is relatively small. The wells need to be sealed with cement, the surface well pads and facilities need to be dismantled, and the soil sealing needs to be removed to some extent. However, some wells must be retained for intervention purposes in the event of ineffective storage. In the case of marine fluid extraction, drilling rigs and subsea infrastructure must be dismantled (Raimi et al. 2021; Torbjørn Vrålstad et al. 2019). The main focus of potential reclamation activities for oil production is on former oil sands production. These are either very close to the surface or still in an area where the surface was disturbed during extraction, requiring extensive remediation (Grant 2008; Sylvain et al. 2019). Reclamation of such areas is currently rare. Geotechnical (Park and Choi 2020), microbiological and natural remedies can be used for remediation (Dhar et al. 2018; Wells and Price 2015). The relevant measures for oil sands have similarities with coal pit reclamation: the main measures are bringing back nature by planting special plants and reducing the impact for the region.

The presentation will focus on how these different types of storage sites can be returned to their original state through remediation and what measures are required for remediation, especially for high impact areas. In addition, research gaps and relevant future business opportunities in the event of site abandonment will be discussed. The presentation will focus on the challenges and successful projects related to the reclamation of areas where oil sands have been extracted, particularly in comparison to the moderate surface mining of brown and hard coal. The geological formation in which oil sands are typically found differs significantly from that of coal, which occurs as a separate mineral. In addition, there are usually different permeabilities and pressure conditions in the respective areas. The talk will highlight these challenges and successful projects.

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References:

Dhar, Amalesh; Comeau, Philip G.; Karst, Justine; Pinno, Bradley D.; Chang, Scott X.; Naeth, Anne M. et al. (2018): Plant community development following reclamation of oil sands mine sites in the boreal forest: a review. In *Environ. Rev.* 26 (3), pp. 286–298. DOI: 10.1139/er-2017-0091.

Grant, Jennifer (2008): Fact or fiction. Oil sands reclamation. Edited by Roland Lines, Dan Woynillowicz, Simon Dyer. Drayton Valley, Alta: Pembina Institute for Appropriate Development (Oil sands fever series). Available online at http://library.arcticportal.org/id/eprint/1491.

Park, Sebeom; Choi, Yosoon (2020): Applications of Unmanned Aerial Vehicles in Mining from Exploration to Reclamation: A Review. In *Minerals* 10 (8), p. 663. DOI: 10.3390/min10080663.

Raimi, Daniel; Krupnick, Alan J.; Shah, Jhih-Shyang; Thompson, Alexandra (2021): Decommissioning Orphaned and Abandoned Oil and Gas Wells: New Estimates and Cost Drivers. In *Environmental Science & Technology* 55 (15), pp. 10224–10230. DOI: 10.1021/acs.est.1c02234.

Raj K. Shrestha; Rattan Lal (2011): Changes in physical and chemical properties of soil after surface mining and reclamation. In *Geoderma* 161 (3), pp. 168–176. DOI: 10.1016/j.geoderma.2010.12.015.

Sylvain, Zachary A.; Espeland, Erin K.; Rand, Tatyana A.; West, Natalie M.; Branson, David H. (2019): Oilfield Reclamation Recovers Productivity but not Composition of Arthropod Herbivores and Predators. In *Environmental entomology* 48 (2), pp. 299–308. DOI: 10.1093/ee/nvz012.

Torbjørn Vrålstad; Arild Saasen; Erling Fjær; Thomas Øia; Jan David Ytrehus; Mahmoud Khalifeh (2019): Plug & abandonment of offshore wells: Ensuring long-term well integrity and cost-efficiency. In *Journal of Petroleum Science and Engineering* 173, pp. 478–491. DOI: 10.1016/j.petrol.2018.10.049.

Wells, Corey M.; Price, Jonathan S. (2015): A hydrologic assessment of a saline-spring fen in the Athabasca oil sands region, Alberta, Canada - a potential analogue for oil sands reclamation. In *Hydrol. Process.* 29 (20), pp. 4533–4548. DOI: 10.1002/hyp.10518.

Yu Feng; Jinman Wang; Zhongke Bai; Lucy Reading (2019): Effects of surface coal mining and land reclamation on soil properties: A review. In *Earth-Science Reviews* 191, pp. 12–25. DOI: 10.1016/j.earscirev.2019.02.015.

Influence of different exposure times of treatment with a microelement in an aquaponic system on hydrochemical indicators and productivity of pepper (Capsicum annuum) cultivated integrated with common carp (Cyprinus carpio)

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Keywords: aquaponics, microelements, exposure time, carp, pepper

ABSTRACT

Information regarding the use of micronutrients to reduce deficiencies in plants grown in aquaponic conditions is limited. Therefore, our goal was to track the influence of the exposure time of Oligo Spectrum® containing microelements on water quality and growth indicators of common carp (Cyprinus carpio) and pepper (Capsicum annuum) cultivated in an aquaponic system. For the experiment, an aquaponics located in a greenhouse with an area of 30 m2 was used, consisting of fish tanks, a mechanical filter with a volume of 1 m3, a moving bed biofilter, a sump and plant raft tanks (8 pcs.). The seedlings were fertilized with liquid microelements twice a week. Microelement fertilization was performed with exposure time of the "Oligo Spectrum" for 2, 4, 6 hours, and the experimental variants were №2, 4, 6, and a control variant (c) - without exposure time of the preparation. During the entire trial, fish mortality was controlled, and at the end of the experiment, the survival rate of the experimental fish was determined. At the end of the trial SGR and FCR were determined. Also, at the end of the experiment, the average stem length, average fruit weight, average yield from each experimental variant, and average root system length were determined. No clear trend was found for the influence of exposure time of the microelement preparation Oligo Spectrum® on the cleaning capacity of the raft tanks in the experimental aquaponic system. The strongest cleaning capacity on ammonia was observed in experimental variant №2, on nitrites - in the control variant (without exposure time of the preparation), on nitrates - in experimental variant №4, and on phosphates - in the experimental variant with 6-hour exposure time of microelements in plant tanks. No negative impact of treatment with microelement preparation on the survival and growth of common carp (C. carpio) grown in the aquaponic system was detected. The stem growth of the cultivated plants was highest in the variant where the exposure time of the microelement preparation in the plant section tanks was 2 hours. The longest root length, largest average fruit weight, and highest average yield were found in experimental variant №6.

Wetland-based solution for sustainable water management in a semiarid irrigation area subject to water use conflict

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Keywords: Wetland-agriculture interactions, regional ecological reconciliation, degraded saline wetland restoration, drainage water reuse, Songnen Plain

ABSTRACT

Although conflicts for water resource between food production and ecosystem conservation have been occurring globally, there is a growing consensus that nature conservation and restoration can provide ecological barriers to food production (Kremen & Merenlender, 2018); however, it remains challenge to ensure the coexistence of natural wetlands and farmlands, and wetlands surviving in agricultural landscape are of particular importance to support biodiversity and sustainable development (Zou et al., 2018), especially delivering water regulation service as green infrastructure offering nature-based solutions (García et al., 2023). In this study, we investigated the water flow and quality of paddy fields, channels and wetlands, and then developed a sustainable water management model based on water balance, InVEST model and empirical formula for salt removal in a semiarid irrigation area (Da'an) of Northeast China, where water diversion projects have been built to develop saline lands into paddy fields in recent years.

Results showed that the total multi-year average ecological water demand and water production of the irrigation district was 19.43 million m^3 and 73.58 million m^3 respectively, while the paddy field water demand for was 110.8 million m^3. Thus, the average annual water transfer required was 56.63 million m^3 considering the efficiently use of precipitation during growing season. The average salinity of drainage water was 157.92 g/m^2. The wetland restored reusing drainage water collection showed saline and nutrient removal efficiency of more than 40% from May to September without significant dieback. Further agricultural reuse of wetland surface water after nutrients/pollutants removal is recommended with pumping facilities.

We highlight that the efficient reuse of water resources should be the main focus in irrigation area development to maintain the basic proportion of different land types to support the ecological stability for agricultural production.

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References:

García, J., Romero, X., Gonzalez-Flo, E., 2023. Nature based-solutions for water reuse: 20 years of performance evaluation of a full-scale constructed wetland system. Ecological Engineering, 188, 106876, https://doi.org/10.1016/j.ecoleng.2022.106876

Kremen, C., Merenlender, A.M., 2018. Landscapes that work for biodiversity and people. Science, 362, 304, http://dx.doi.org/10.1126/science.aau6020

Zou,Y., Duan, X., E, M., Sun, M., Xue, Z., Lu, X., Jiang, M., Yu, X., 2018. Water use conflict between wetland and agriculture. Journal of Environmental Management, 224, 140-146, https://doi.org/10.1016/j.jenvman.2018.07.052

Tailings Management Facilities: Risk Reduction

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Keywords: criteria, hazardous waste, mining waste, regulations, requirements

ABSTRACT

The mining industry is well-developed in Armenia, in particular, extraction of zinc, copper, molybdenum, and gold. Elaboration of ore deposits faces a number of problems that are caused by the negative impact on the environment. Amongst the mining wastes, enrichment tailings are mostly hazardous, as they accumulate in tailings management facilities alongside with the mining waste that contains toxic enrichment substances: NaCl, KCN, mercury.

According to the degree of danger, all tailings dumps of metallurgical minerals of the Republic of Armenia actually belong to groups of the 2nd and 3rd degree of hazard. These are tailings of Ararat Gold Recovery Plant, tailings of processing lead, zinc, copper, molybdenum and copper tails processing.

Partially preserved tailings management facilities of non-ferrous metals also pose hazards.

Hazards of a tailings dump are evaluated according to the following criteria:

- Toxicity and eco-toxicity of materials to the dump;
- Hazards to the aquatic environment occurring in relation with impacts of discharged materials apart from the toxic exposure (e.g., pH, chemical oxygen demand, mineralization, dispersed materials);
- Hazards of floods due to presence of free liquids in a tailings dump;
- Hazards connected with physical / mechanical properties and behaviour of stored solid materials (slime transport and / or liquation events) in case of an accident;
- Hazards occurring in case of soil contamination by tailings/ liquid wastes.

In order to reduce risks of impacts produced by a tailings dump towards the human health and the environment it is necessary to perform the following measures:

- To reduce amounts of generated wastes through development and implementation of new technology processes;
- To prevent wastes harmful impacts towards human health and the environment;
- To implement direct, secondary and alternative use of mining wastes with material or energy resource value;
- To reduce or eliminate application of harmful substances and processes;
- To establish procedure for classification of mining wastes and their management facilities according to hazard.

Armenia adopted a number of regulations, by-laws to regulate mining wastes for prevention of their harmful effects to human health and the environment. Here belong:

- Criteria set forth on the best available techniques;
- Technical requirements and standards for mining waste management facilities, as well as mining waste management and processing;

- Procedure for mining waste recycling; procedure for classification of mining waste and mining waste management facilities according to hazard;
- Procedure for determination of the maximum admissible concentrations / limits of hazardous chemicals required for processing of ore mineral resources.

All mentioned legal acts regulate issues of environmentally safe management of mining waste, its processing, environmental protection against pollution caused by mentioned waste through introduction of the best technologies, as well as classification of mining waste and its facilities.

References:

Law of the Republic of Armenia "On Wastes" (No. 159-N dated November 24, 2004)

Safety guidelines and good practices for tailings management facilities. UNITED NATIONS ECONOMIC COMMISSION FOR EUROPE. New York and Geneva, May 2014. 42p. Printed at United Nations, Geneva – GE.13-26665 – April 2014 – 696 – ECE/CP.TEIA/26
https://unece.org/DAM/env/documents/2014/TEIA/Publications/1326665_ECE_TMF_Publication.pdf

Decision of the Government of the Republic of Armenia "On establishing the procedure for mining waste and mining waste management facilities classification according to hazard" (No. 689-N of June 15, 2017).

Order of the Minister of Nature Protection of the Republic of Armenia "On approval of the procedure for determination of the maximum admissible concentrations / limits of hazardous chemicals required for processing of ore mineral resources" (No. 256-N of August 1, 2017).

Decision of the Government of the Republic of Armenia "On establishing technical requirements and criteria set forth to mining waste management facilities and mining waste management and processing" (No. 985-N of August 10, 2017).

Efficient removal and electrochemical detection of heavy metals by utilizing heavy-metal-tolerant bacteria from sludge

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Keywords: Heavy metal, Heavy-metal-tolerant bacteria, Bioremediation, Electrochemical detection, Utilization of bioresource.

ABSTRACT

The escalating industrialization has led to the emission of the emission of heavy metal contaminants into environment. These heavy metals are non-degradable and can accumulated in the food chain, posing a serious threat to human health. Heavy metals like lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg) are highly toxic even in small dose and can cause irreversible harm to various organs systems[1]. () Moreover, high levels of copper (Cu) have been identified as carcinogen[2]. Consequently, it is crucial to devise efficient and cost-effective methods for detection and eliminating these toxic pollutants. In this context, microorganisms that can survive in heavy metal-polluted habitats have developed numerous strategies to remediate these pollutants[3]. For example, sulfate-reducing bacteria (SRB) can trigger the formation of metal sulfide precipitates from dissolved heavy metals[4], while phosphorus-accumulating bacteria (PAB), such as, *Citrobacter freundii* (*C. freundii*) can store heavy metals in intracellular polyphosphate (polyP) granules[5]. These bacteria serve as natural factories for immobilization and transformation of heavy metals. Therefore, our study aims to utilize SRB and *C. Freundii* cultivated from sludge to treat and detect heavy metals, and accesses their application potentials.

Heavy metal removal from environmental contamination induced by SRB has become a promising approach due to its high efficiency and green routine. However, additional carbon resource is a necessary for the bio-conversion system, thus incurring higher cost[6]. Herein, we used *Hydrocotyle verticillate* fermentation broth as carbon source for improving removal efficiency and reducing costs. The sludge enriched with SRBs was inoculated to anaerobic sequential batch reactor (ASBR) containing *Hydrocotyle verticillate* fermentation broth. Our results demonstrated that, compared to commercial carbon resources (e.g., glucose, sucrose and sodium acetate), the organic substrates in *Hydrocotyle verticillate* fermentation broth provided more accessible electrons for SRBs growth. As the initial COD value was 300 mg/L, the organic substrates were taken up 85.8% after reaction. As the COD/SO_4^{2-} ratios were 1.2, 5.0 and 7.0, the maximal sulfate reduction rates were 24.4%, 43.6% and 60%, respectively. At the concentration of 1 mg/L, Cd^{2+}, Cu^{2+}, Pb^{2+} and Ni^{2+} were removed up to 95.2%, 98.7%, 93.0% and 89.6%, respectively. Our control experiments with dead SRBs showed that heavy metals were primarily removed through biotransformation rather than biosorption. Furthermore, we found that even at high metal ion concentrations (10 mg/L), more than 90% removal efficiency was achieved, and the activity of SRBs was not inhibited. These findings suggest that *Hydrocotyle verticillate* fermentation broth can serve as an effective carbon source for heavy metal removal using SRBs, which could have significant implications for cost-effective and sustainable environmental remediation strategies.

We also developed an electrochemical sensor for detecting heavy metals using the enrichment mechanism of *C. freundii*, in which the polyP produced by *C. freundii* was used as a core component. The electron produced by *C. freundii* metabolism was utilized to reduce graphene oxide, which self-assembled into a three-dimensional reduced graphene oxide (rGO) network that acted as the electrode substrate. The polyP was in-situ generated by living bacteria on the rGO nanosheet, and was characterized by SEM and TEM, showing even distribution on rGO in the form of granules. For the detection of heavy metal ions, numerous functional groups from polyP played the major role in the coordination with the cations, and rGO significantly enhanced electrochemical response signals due to its high electrical conductivity. This electrochemical sensor based on polyP/rGO allowed for simultaneous determination of Pb^{2+} and Cu^{2+} with

detection limits (LOD) of 1.6 nM and 0.9 nM, respectively, while the LODs were 2.4 nM for Pb^{2+} and 1.1 nM for Cu^{2+} by individual detection. Moreover, the polyP/rGO electrode displayed excellent selectivity for target analytes in the presence of multiple interfering metal ions (e.g., K^{+}, Zn^{2+}, Ni^{2+}, Mn^{2+}, Fe^{3+}, Co^{2+}, Cd^{2+}, Mn^{2+}, Ag^{+} and Cr^{3+}) and demonstrated superior data reproducibility. The recovery rate within 89.4%-107.3% also showed the satisfactory accuracy in analyzing real samples.

In this study, SBRs demonstrated notable removal capability against various heavy metals, employing plant fermentation broth as a carbon source. Additionally, the polyP from *C. freundii*, a key constituent of an electrochemical sensor, showed robust sensitivity to heavy metals in wastewater. Alternative to chemical techniques, biological methods possess lower energy consumption, less post-treatment and the potential of recovering valuable elements, which is suitable for practical application. Therefore, utilizing heavy metal tolerant bacteria, specifically SRB and PAB, presents a viable, sustainable and cost-effective approach to mitigating and monitoring metal contaminations in the natural surroundings.

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References:

Kadim, M.K., Risjani, Y., 2022. Biomarker for monitoring heavy metal pollution in aquatic environment: An overview toward molecular perspectives. Emerging Engineering 8, 195-205, https://doi.org/10.1016/j.emcon.2022.02.003

Ding, Q., Li, C., Wang, H., Xu, C., Kuang, H., 2021. Electrochemical detection of heavy metal ions in water. Chemical Communication 57, 7215-7231, https://doi.org/10.1039/D1CC00983D

Priya, A. K., Gnanasekaran, L., Dutta, K., Rajendran, S., Balakrishnan, D., Soto-Moscoso, M., 2022. Biosorption of heavy metals by microorganisms: Evaluation of different underlying mechanisms. Chemosphere 7, 135957, https://doi.org/10.1016/j.chemosphere.2022.135957

Zhang, Z., Zhang, C., Yang, Y., Zhang, Z., Tang, Y., Su, P., Lin, Z., 2022. A review of sulfate-reducing bacteria: Metabolism, influencing factors and application in wastewater treatment. Journal of Cleaner Production 34109, https://doi.org/10.1016/j.jclepro.2022.134109

Kulakovskaya, T., 2018. Inorganic polyphosphates and heavy metal resistance in microorganisms, World Journal of Microbiology and Biotechnology 34, 1-8. https://doi.org/10.1007/s11274-018-2523-7

Ayangbenro, A.S., Olanrewaju, O.S., Babalola, O.O., 2018. Sulfate-reducing bacteria as an effective tool for sustainable acid mine bioremediation. Frontiers in Microbiology 9, 1986. https://doi.org/10.3389/fmicb.2018.01986.

Effect of Reclamation on the Vertical Distribution of SOC and Retention of DOC in the Wetland landscapes in the Sanjiang Plain, Northeast China

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Keywords: Soil organic carbon (SOC), dissolved organic carbon (DOC), reclamation, wetlands

ABSTRACT

Worldwide biogeomorphic wetlands experience human-induced annual loss at the average rates of around 1%, estimating that associated carbon losses amount to 0.5 Pg C per year that are equivalent to 5% of the estimated overall anthropogenic carbon emissions (Temmink et al., 2022). The large reservoirs of soil organic carbon (SOC) at deeper soil (well over a metre) mean that this largely ignored carbon fraction could play a significant role in future climate change (Wilson et al., 2016). An important source of deep SOC in wetland soil is the vertical migration of dissolved organic carbon (DOC). Since the effective retention time of soil carbon is several decades, the DOC must enter the stable reservoir or enter the deeper soil layer. DOC leaching plays an important role in the process of carbon migration from the surface soil and fixation with soil minerals. Much of the loss of the DOC in soil solution is retained by the soil to become more stable carbon. Since the 1950s, the marsh wetland of Sanjiang Plain has undergone large-scale reclamation for many times, and the phenomenon of wetland-farmland conversion is serious. After reclamation, soybean or rice is planted. This study analyzed the distribution of organic carbon in soil profile of the marsh wetland of the Sanjiang Plain and the soybean field and paddy field reclaimed from natural wetlands, and the DOC contents in soil solutions at different soil depths. The objective was to analyze the vertical distribution of SOC contents and densities before and after wetland reclamation, as well as the soil's retention of DOC, and the contents and densities of SOC in soil profiles and DOC of soil solution in different soil depths in wetland, soybean and paddy fields were determined to investigate how reclamation of wetland for soybean and rice farming impacts vertical distribution of SOC and retention of DOC.

Results showed that the SOC contents in 0-10, 10-20, 20-30 and 30-40 cm soil layers in soybean and paddy fields were 79.07% and 82.01%, 79.01% and 82.28%, 79.86% and 92.90%, 37.49% and 78.05% respectively lower than those in natural wetland. Before and after reclamation, SOC contents in soil layers deeper than 40 cm were not significantly different. The SOC densities in soybean and paddy fields were 25.50% and 47.35% respectively lower than those in natural wetland. However, either in wetland or farmlands, most of the SOC storage in 0-100 cm soil layer was stored in the upper 0-50 cm soil layer. The relationships between SOC content and soil depth in wetland and two farmlands could be described by exponential functions. Wetland reclamation did not change the variation of SOC content with soil depth. The retention of DOC was more obvious for soybean field than wetland and paddy field, and that was roughly the same for wetland as paddy field.

It is concluded that wetland reclamation changed SOC contents in wetland profiles, but did not change the variation law of SOC with soil depth.

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References:

Temmink, R.J.M., Lamers, L.P.M., Angelini, C., et al. (2022). Recovering wetland biogeomorphic feedbacks to restore the world's biotic carbon hotspots. Science, 376, 594. https://www.science.org/doi/10.1126/science.abn1479

Wilson, R., Hopple, A., Tfaily, M., et al. Stability of peatland carbon to rising temperatures. Nat Commun 7, 13723 (2016). https://doi.org/10.1038/ncomms13723

Physics of sound and SDGs: Raising awareness for the dangers of noise pollution

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Keywords: Environmental noise, physics of sound, education for sustainable development goals, noise measurement sensors;

ABSTRACT

This work intends to raise awareness for the dangers of noise pollution, and its consequences for health, among other issues, as well as to present measures needed to prevent its consequences, including this theme as part of the awareness underneath the Sustainable Development Goals (SDGs). Noise is defined as an unwanted and/or harmful sound that disturbs and annoys people. When excessive and prolonged, it can cause hearing loss; disruption of sleep and speech communication (that can lead to accidents); cardiovascular diseases and death, due to stress-induced problems. In fact, there are several sources of noise such as road traffic, railways, aircraft, wind turbines, or leisure noise, including personal listening devices. More than 100 million are affected by road traffic noise, and also more than 1.6 million healthy years of life are lost, as a result of road traffic noise in western Europe alone (WHO, 2018). This theme is related to the 3rd SDG goal "Ensure healthy lives and promote well-being for all at all ages", where one target is "By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water, and soil pollution and contamination." (UN SDG, 2023; Costa et al., 2022).

Thus, it is crucial to diagnose dangerous situations such as excessive noise levels leading to increasing malaise which could ultimately lead to death. In this regard, effective noise control measures such as noise mapping, technical, planning, behavioural, and educational solutions, should be implemented (Oyedepo et al., 2019). In addition, it is critical to sensitize the population to the dangers related to noise pollution, as well as to pressure political decision-makers on the importance of complying with legislation to prevent the risks associated with excessive noise. With noise prevention, well-being is improved as well as the reduction of accidents. This results in better health conditions, higher productivity, and consequently reduced health and labour costs, which is a great social and economic benefit for countries. To achieve these goals, it is crucial to develop partnership with organizations to develop measures and projects that contribute to the SDG United Nations agenda. For example, with higher education institutions, municipalities, clusters of schools, among others, in a joint collaborative effort that is a driver for change to improve the well-being and health of all.

This research presents a project that results from partnerships with a higher education institution from Portugal, teachers training centres, clusters of schools, and municipalities. On the one hand, the project aims to sensitise the younger generations for the need to develop SDG practices. In this regard, it recognizes the role of schools in this matter, and the role of teachers in this mission, which is why they need professional development that provides them with knowledge and skills to guide students, who ultimately will influence their family and friends. On the other hand, collaboration with municipalities is required to develop projects, for example to diagnose dangerous situations through technological solutions such as placing noise measurement sensors at strategic locations. Furthermore, preventive measures need to be discussed and implemented when dangerous situations for health and well-being have been detected.

Regarding technological solutions related to measurement sensors, in terms of implementation, the long-term ultimate objective will ideally be to take advantage of wireless systems communications (Hart & Martinez, 2006); technical developments in the fields of: low-cost and low energy consumption processors; electric batteries, etc.; to acquire signals from microphones, and develop a low-cost sensor network for measuring environment sound. The involvement of the community in this process will be

important to create conscience of the problem. Information on the existence of environmental noise threatening people's health and work performance is essential to make the population and political decision-makers aware of the need for preventive measures to improve people's living conditions, one example is Zambon et al. (2015).

In conclusion, there are several SDGs addressed in this study. In addition to the aforementioned 3rd goal, the 4th goal "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all" is approached. Moreover, these goals are also related to SDG 11: "Make cities and human settlements inclusive, safe, resilient and sustainable"; and SDG 17: "Strengthen the means of implementation and revitalize the global partnership for sustainable development", among others, like SDG 14 and 15, by calling attention to sound pollution and its consequences, and for the need to prevention measures. Therefore, partnerships with higher education institutions and other organizations can have a critical role in the community, to help contributing to the United Nation SDGs agenda.

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References:

Costa, M. C., Ferreira, C. A., & Pinho, H. J. (2023). Physics of Sound to Raise Awareness for Sustainable Development Goals in the Context of STEM Hands-On Activities. *Sustainability*, *15*(4), 3676. DOI: https://doi.org/10.3390/su15043676

Hart, J. K., & Martinez, K. (2006). Environmental sensor networks: A revolution in the earth system science?. *Earth-Science Reviews*, *78*(3-4), 177-191. DOI: https://doi.org/10.1016/j.earscirev.2006.05.001

Oyedepo, S. O., Adeyemi, G. A., Olawole, O. C., Ohijeagbon, O. I., Fagbemi, O. K., Solomon, R., ... & Nwaokocha, C. N. (2019). A GIS–based method for assessment and mapping of noise pollution in Ota metropolis, Nigeria. *MethodsX*, *6*, 447-457. DOI: 10.1016/j.mex.2019.02.027

UN SDG (United Nations Sustainable Development Goals) Available online: https://sdgs.un.org/goals (accessed on May 25, 2023).

World Health Organization (2019). *Environmental noise guidelines for the European Region*. Regional Office for Europe, Ed.; WHO TEAM C. ISBN 9789289053563

Zambon, G., Benocci, R., Bisceglie, A., Roman, H. E., & Bellucci, P. (2017). The LIFE DYNAMAP project: Towards a procedure for dynamic noise mapping in urban areas. *Applied Acoustics*, *124*, 52-60. DOI: https://doi.org/10.1016/j.apacoust.2016.10.022

Deep Eutectic Solvent Pretreatment of Olive Tree Biomass

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Keywords: Olive tree pruning biomass, deep eutectic solvent, pretreatment, phenolics, carbohydrates

ABSTRACT

Anatolia, has been home to the olive tree for 6000 years. Olive cultivation is carried out in more than 40 countries (Yılmaz and Bahtiyar 2020), especially in Mediterranean countries such as Turkey, Tunisia, Morocco, Algeria, Egypt, Spain, Italy, Greece, and Portugal. The land devoted to olive-tree cultivation around the world is around 12×10^6 ha (Messina and Modica, 2022). Olive tree pruning biomass (OTPB) is an agricultural residue generated yearly in olive tree cultivation by the removal of un-productive branches to prepare the tree for next harvest. This operation results in a large amount of biomass (OTPB) that must be removed from the fields. An average of 3 tons of OTPB is generated from a hectare of olive orchard, leading to producing more than 3.3×10^7 t biomass (García Martín et al. 2020; Martínez-Patiño et al. 2017). Generally, OTPB is either ploughed into the soil or left on the land to be incinerated, which could be utilized for the production of value-added products.

Lignocellulosic materials are generally composed of cellulose (40-50%), hemicellulose (25-30%) and lignin (15-20%). The presence of lignin in the cell walls gives rigidity to lignocellulose, which prevents the breakdown of structural polysaccharides. Even though different pretreatment methods have revealed a vast amount of knowledge about pretreatment of olive tree pruning waste, it still remains a serious challenge to break the recalcitrance of biomass through an energetically efficient and environmentally friendly process.

Application of greener solvents in chemical processes, which reduces the health, safety and environmental issues has drawn much attention in recent years. Deep Eutectic Solvents (DES) are a new generation of green solvents which could be utilized for treating the cellulosic biomass. Different lignocellulosic biomass such as corn cob, rice straw, switchgrass, wheat straw and beech wood (Satlewal et al. 2018; Jablonsky et al. 2019) were reported to be pretreated effectively with various DES. However, research regarding deep eutectic solvent pretreatment of OTPB is lacking in literature.

Against this background, the main objective of this study was to investigate the effect of DES pretreatment on OTPB. The treatment was carried out using DES (choline chloride and formic acid (1:2 molar ratio)) at different temperatures (90, 110 and 130 °C) and treatment times (20, 40 and 60 min) at a solid to solvent ratio of 1:10 (g/mL). The percentage of solids recovered during the pretreatment was in the range of 40.6–87.33%. Solid recovery was decreased significantly as the temperature and pretreatment time was increased. The highest total phenolic content (143 mg GAE / g dry OTPB) was observed at 130 °C-40 min. Pretreatment temperature had a significant impact on the release of phenolic compounds from olive tree biomass. The effect of process conditions on the different sugar yields were also analyzed using a Dionex ICS-6000 system (Thermo Scientific, USA) with pulsed amperometric detection (HPAEC–PAD). The sugar concentration in the liquid fraction was increased as the severity of the pretreatment was elevated. It can be concluded that DES treatment was an effective green technology to destruct the structure of OTPB.

References

García Martín, J. F., Cuevas, M., Feng, C. H., Álvarez Mateos, P., Torres García, M. and Sánchez, S. 2020. Energetic valorisation of olive biomass: Olive-tree pruning, olive stones and pomaces. Processes, 8(5), 511.

Jablonsky, M., Haz, A. and Majova, M. 2019. Assessing the opportunities for applying deep eutectic solvents for fractionation of beech wood and wheat straw. Cellulose 26:7675–7684.

Marquina, J., Colinet, M. J. and Pablo-Romero, M. D. P. 2021. The economic value of olive sector biomass for thermal and electrical uses in Andalusia (Spain). Renewable and Sustainable Energy Reviews, 148, 111278.

Martínez-Patiño, J. C., Ruiz, E., Romero, I., Cara, C., López-Linares, J. C., Castro and E. 2017. Combined acid/alkaline-peroxide pretreatment of olive tree biomass for bioethanol production. In Bioresource Technology 239, 326–335.

Messina, G. and Modica, G. 2022. Twenty years of remote sensing applications targeting landscape analysis and environmental issues in olive growing: A review. Remote Sensing, 14(21), 5430.

Satlewal, A., Agrawal, R., Bhagia, S., Sangoro, J. and Ragauskas, A. J. 2018. Natural deep eutectic solvents for lignocellulosic biomass pretreatment: Recent developments, challenges and novel opportunities. Biotechnology advances, 36(8), 2032-2050.

Yılmaz, F. and Bahtiyari, M. İ. 2020. Antibacterial finishing of cotton fabrics by dyeing with olive tree leaves fallen during olive harvesting. Journal of Cleaner Production, 270, 122068.

The effect of external carbon source type and dose on nitrogen and phosphorus removal in Sequencing Biofilm Batch Reactor (SBBR)

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Keywords: external carbon source, nitrogen and phosphorus removal, biofilm reactor

ABSTRACT

Introduction It is estimated that the area of soilless cultivation in the world is 95,000 ha [1]. In the European Union, over 80% of the area of soilless cultivation is located in 5 countries (Netherlands, Spain, Poland, Italy and France). In Poland, the area of this kind of cultivation is over 5,300 ha [2].

Due to the specific composition of wastewater discharged from greenhouses with soilless cultivation of plants, characterized by a high concentration of nitrates and phosphorus and a low concentration of organic compounds, a useful technological solution for their treatment may be biofilm reactors with an external source of carbon application. This was confirmed by research by Rodziewicz et al. [3], which showed that the use of an aerobic electrobiological rotating contactor to which sodium acetate was fed allowed to remove 99.8% of phosphorus and 53.4% of nitrogen from synthetic greenhouse wastewater. The unsatisfactory level of nitrogen concentration removal in the aerobic reactor showed that a technological solution should be sought where oxygen conditions could be controlled and thus ensure not only high efficiency of P removal but also N removal. The Sequencing Batch Biofilm Reactor (SBBR) is just such a reactor [4].

The aim of the work was to determine the effect of the type and dose of an external source of organic carbon on the efficiency of nitrogen and phosphorus removal from wastewater from the greenhouses for soilless cultivation of tomatoes on mineral wool in a sequencing batch reactor with biofilm (SBBR).

Research methodology Laboratory SBBR reactors with a volume of 2L and five discs with a diameter of 12 cm were used in the research. Stainless steel discs were mounted on a rotating vertical shaft (fig. 1).

Fig. 1. Research model

As an external carbon source, sodium acetate and acetic acid were used, which are proven substrates used to support the removal of biogenic compounds from wastewater. The organic substrate was fed to the reactors in 3 doses, which expressed in the C/N ratio were 1, 1.5 and 2, respectively. The external source of carbon to the reactors was supplied in the form of a solution once in the amount of 100 cm^3 per day. The duration of the cycle was 24 h (fig. 2).

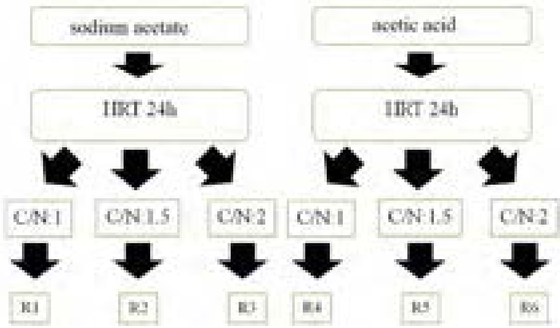

Fig. 2. Research scheme

3. Results The nitrogen and phosphorus concentrations in the wastewater supplied to the reactors were 479 ± 10.4 mgN/L and 88 ± 4.9 mg P/L, respectively. It was found that the efficiency of nitrogen compounds removal in the reactors increased with the increase of the carbon dose for both used substrates. The maximum was 98.6±0.4% with the use of sodium acetate and 98.5±0.4% with the use of acetic acid at a dose of organic compounds of C/N 2. The lowest removal efficiency with both acetic acid (41.1±7.9%) and sodium acetate (44.6±3.0%) was obtained at the lowest C/N dose of 1 (fig. 3).

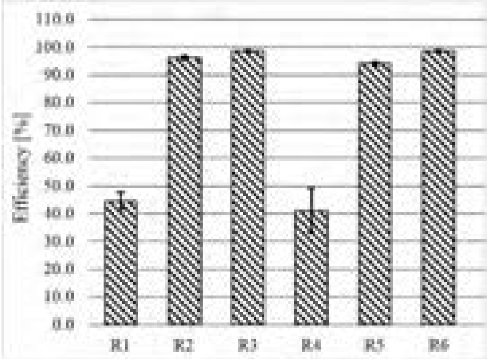

Fig. 3. Efficiency of nitrogen compounds removal

Studies have shown that the average efficiency of phosphorus removal in reactors in which sodium acetate was used was at a very similar level and ranged from 93.1±1.1% in R1 to 93.6±1.1% in R3. The lowest phosphorus removal efficiency was obtained for acetic acid at a C/N ratio of 1. The TP removal efficiency in this reactor was 72.0±3.5%. In the R5 and R6 reactors, as in the reactors with sodium acetate, a slight increase in the efficiency of phosphorus removal was observed with the increase of the C/N ratio and they amounted to 92.1±1.9% and 92.9±1.1%, respectively.

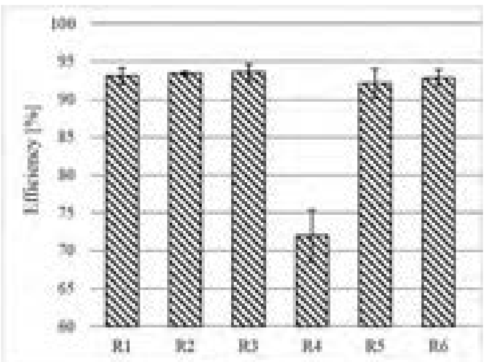

Fig. 4. Efficiency of phosphorus removal

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References

[1] Gullino, M.L.; Gilardi, G.; Garibaldi, A. Ready-to-Eat Salad Crops: A Plant Pathogen's Heaven. Plant Dis 2021, 103, 2153–2170.

[2] Incrocci, L.; Thompson, R.B.; Fernandez-Fernandez, M.D.; De Pascale, S.; Pardossi, A.; Stanghellini, C.; Rouphael, Y.; Gallardo, M. Irrigation Management of European Greenhouse Vegetable Crops. Agric Water Manag 2020, 242, 106393.

[3] Rodziewicz, J.; Mielcarek, A.; Janczukowicz, W.; Jóźwiak, T.; Struk – Sokołowska, J.; Bryszewski, K. The Share of Electrochemical Reduction, Hydrogenotrophic and Heterotrophic Denitrification in Nitrogen Removal in Rotating Electrobiological Contactor (REBC) Treating Wastewater from Soilless Cultivation Systems. Science of The Total Environment 2019, 683, 21–28.

[4] Kłodowska, I.; Rodziewicz, J.; Janczukowicz, W.; Cydzik-Kwiatkowska, A.; Rusanowska, P. Influence of Carbon Source on the Efficiency of Nitrogen Removal and Denitrifying Bacteria in Biofilm from Bioelectrochemical SBBRs. Water 2018, 10, 393.

The influence of the method of organic substrate dosing on the efficiency of Sequencing Biofilm Batch Reactor (SBBR)

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Keywords: Sequencing Biofilm Batch Reactor, soilless cultivation, organic substrate dosing, nitrogen and phosphorus removal efficiency

ABSTRACT

Introduction

By definition, soilless cultivation is carried out without the use of soil in which the roots of the plants grow in the growing medium - *substrate-culture soilless (SCS*) or are suspended in a nutrient solution - *liquid-culture soilless (LCS)* [1].

Wastewater from soilless cultivation is generated mostly during cultivation in the open system. In this system, the excess of the medium is discharged in an untreated form into the environment [2]. This is a practice commonly used in the world, including Poland [3]. The concentration of nitrogen and phosphorus in the greenhouse effluent can be up to 600 mgN/L and up to 400 mg P/L, respectively [3-5]. Therefore, this wastewater requires an external carbon source during biological treatment. The method of dosing the organic substrate affects the momentary loading of the reactor and may affect not only its use but also the efficiency of the processes [6].

The aim of the work was to determine the effect of the method of dosing the organic substrate into a batch reactor with a biofilm on the efficiency of nitrogen and phosphorus removal processes.

Research methodology

The research was carried out on laboratory sequencing batch biofilm reactors (SBBRs) with a volume of 2L with five discs with a diameter of 12 cm (reactors R1-R6). Stainless steel discs were mounted on a rotating vertical shaft (fig. 1). The study used real wastewater from a greenhouse with an area of approximately 200,000 m^2, where tomatoes are grown on a mineral wool substrate [3]. The concentration of nitrogen and phosphorus in the wastewater was up to 570 ± 8.5 mgN/L and 147.3 ± 7.7 mg P/L, respectively.

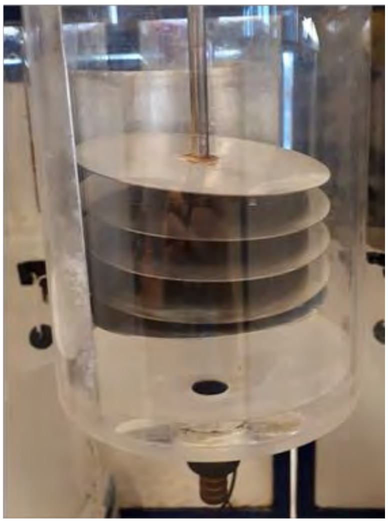

Fig. 1. Research model

Wastewater was fed to the reactor once a day. Cycle duration was 24 h (HRT=24h). Sodium acetate (R1, R2, R3) and acetic acid (R4, R5, R6) were used as the external carbon source. The dose of organic substrate expressed as a C/N ratio was 1.5. Three methods of dosing organic substrates were used:

- dosing 100% of the substrate dose (R1, R4) at the beginning of the cycle,
- dosing 50% of the substrate dose at the beginning of the cycle, another 50% after 12 hours of reactor operation (R2, R5),
- even dosing of the substrate within a 24-hour cycle (R3, R6).

Results

It was found that in reactors using sodium acetate (fig. 2), regardless of the method of dosing the organic substrate, over 97% efficiency of nitrogen removal was obtained (from 97.01±0.52% in R1 to 97.17± 0.63% in R3). In reactors with acetic acid, the efficiency was slightly lower, ranging from 95.87±0.68% (in R5) to 96.28±0.58% (in R6).

Studies have shown that, regardless of the method of substrate dosing, over 90% efficiency of phosphorus removal was obtained (fig. 3). The efficiency in the case of sodium acetate was higher compared to the variant with acetic acid and ranged from 96.0±0.4% in R1 to 96.2±0.8% in R3. In the variant with acetic acid, the highest efficiency of 96.0±0.6% was obtained using 100% of the organic substrate dose at the beginning of the cycle. On the other hand, the lowest efficiency was obtained in R5 (94.0±1.1%), where the dose of organic compounds in the amount of 50% of the dose taken was introduced at the beginning of the cycle, and another 50% after 12 hours of reactor operation.

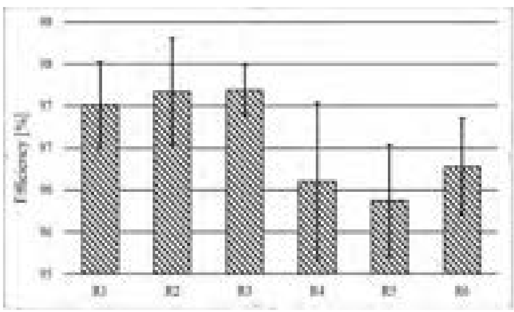

Fig. 2 Efficiency of nitrogen removal

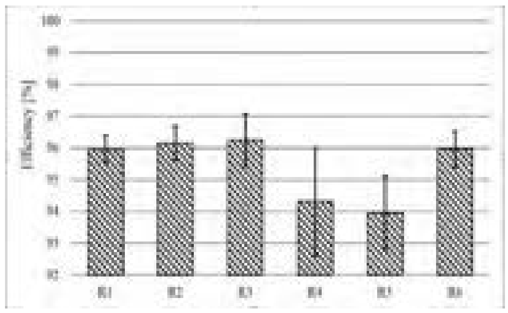

Fig. 3 Efficiency of phosphorus removal

Irrespective of the applied method of organic carbon dosing, high efficiency of total nitrogen and phosphorus removal were obtained. Sodium acetate turned out to be more effective as a carbon source in nutrients removal. Sodium acetate was also more effective with respect to phosphorus.

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References:

[1] Gong, L.; Luo, L.; Gao, J.; Xiong, Y.; Chen, C.; Gan, H.; Song, H.; Velazquez-Gonzalez, R.S.; Garcia-Garcia, A.L.; Ventura-Zapata, E.; et al. A Review on Hydroponics and the Technologies Associated for Medium- and Small-Scale Operations. Agriculture 2022, 12, 646.

[2] Breś, W. Estimation of Nutrient Losses from Open Systems to Soil during Horticultural Cultivation. Pol J Environ Stud 2009, 18, 341–345.

[3] Mielcarek, A.; Rodziewicz, J.; Janczukowicz, W.; Dobrowolski, A. Analysis of Wastewater Generated in Greenhouse Soilless Tomato Cultivation in Central Europe. Water 2019, 11, 2538.

[4] Saxena, P.; Bassi, A. Removal of Nutrients from Hydroponic Greenhouse Effluent by Alkali Precipitation and Algae Cultivation Method. Journal of Chemical Technology & Biotechnology 2013, 88, 858–863.

[5] Richa, A.; Touil, S.; Fizir, M.; Martinez, V. Recent Advances and Perspectives in the Treatment of Hydroponic Wastewater: A Review. Rev Environ Sci Biotechnol 2020, 19, 945–966.

[6] Metcalf & Eddy, Inc. Wastewater Engineering: Treatment and Resource Recovery 5th Ed. 2014.

Aerobic DNRA-performing *Neobacillus* sp. strain Isolated from Rice Paddy Field Soil, Republic of Korea

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ABSTRACT

Dissimilatory nitrate reduction to ammonium (DNRA) refers to the microbial enzymatic reaction in which NO_3^- / NO_2^- is reduced to produce NH_4^+. NO_3^- can be easily lost from agricultural soil via leaching by rainfall, thus, DNRA can decrease N loss and retain biologically available nitrogen in soil, leading to more sustainable farming without excessive application of N fertilizers. DNRA has been believed to occur under anaerobic conditions, however, *Pseudomonas putida* strains were recently reported to perform DNRA with presence of oxygen. In this study, several *Neobacillus* spp. strains performing denitrification and/or DNRA were isolated from rice paddy field. Interestingly, *Neobacillus* sp. PS3-36 among them was observed to perform DNRA under aerobic condition. The DNRA functional gene, *nirB*, was detected from the strain PS3-36 by conventional PCR using the oligonucleotide primers designed in this study. With identical primers used for *nirB* detection, transcripts of *nirB* were analyzed for aerobic and anaerobic cultivation. Whole genome of the strain PS3-34 was sequenced to investigate molecular characteristics of the aerobic DNRA-performing soil bacterium. Knowledge of aerobic DNRA microbes can be a microbiological solution for N loss at the surface aerobic soil layer caused by leached NO_3^- produced from aerobic nitrification.

SIGNIFICANCE OF SOIL TYPE AND APPLIED FERTILIZATION ON THE CONTENT AND UPTAKE OF MACROELEMENTS WITH SUNFLOWER BIOMASS IN POT EXPERIMENTS

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Keywords: soils; fertilization norms; N, P, K, Si, Ca, Mg uptake; sunflower.

ABSTRACT
Sunflower is a major oilseed crop in Bulgaria. New hybrids and promising sunflower lines, distinguished by a number of their characteristics and physiological requirements, are constantly entering the practice. In terms of nutrient supply, hybrids with the highest requirements are followed by varieties with high oil content, while those with low oil content are the least demanding.
The nutrient requirements for yield formation depend both on the specific soil and climatic conditions of the area and on several other factors. The importance of fertilization is paramount (Ahmad I., et al., 2017; Zichuan Li, et al., 2018). Sunflower responds well to nitrogen fertilization - excess nitrogen lowers oil content and lowers plant resistance to disease. Appropriately balanced phosphorus and potassium fertilization increase yield and oil content (Nenova L., Mitova V., 2018). The potassium requirements of sunflower are high - 7-11 kg per 100 kg of seed, i.e. 5-2 times more than nitrogen and 4-5 times more than phosphorus. Potassium increases the absolute weight and fat content of the seeds (Nikolova M., 2010). Experiments conducted in our country show an increase in fat yield under the influence of potassium fertilization.
Silicon (Si) is not classified as an essential element for plants, but numerous studies have described its beneficial effects under various soil and climatic conditions, including low levels of plant-available forms of silicon. The application of Si shows the potential to increase the availability of nutrients in the rhizosphere and their uptake by plants (Pavlovic J., et al., 2021). In the study (Peixoto et al., 2022) a higher total leaf area of Si-treated plants leads to increased overall CO2 uptake by the plant. Plants treated with Si have an increase of 24-39% in biomass yield.
Determination of optimal nutrient regime for crops requires establishing the export and consumption of nutrients to form a unit of production, and their balance in the soil for different soil conditions.
The study aim is to evaluate the effect of different soil types – Alluvial-meadow and Leached smolnitsa, different norms and combinations of nitrogen, phosphorus, potassium, and silicon fertilizers on the content and uptake of some main macro elements with medium-early hybrid Sunflower (Helianthus annuus L.) - Sumiko HTS.

Materials and methods

In the spring of 2021, a vegetation fertilizer trial with a test crop of an early to mid-early hybrid of sunflower (Helianthus annuus L.) - Sumiko HTS of Sinjenta was set up and established. The initial soils are Alluvial-meadow soil and Leached smolnitza supplied by the experimental field in Tsalapitsa, Plovdiv region, and in Bozhurishte, Sofia. According to the classification of soils in Bulgaria (Koinov V., 1987), they are defined as Eutric Fluvisol – Fleu and Haplic vertisols (FAO, 2015). The first is characterized by a neutral soil reaction in the plowing horizon (pHH2O 7.4), with a low content of total (0. 052%) and mineral nitrogen (11.52 mg N/kg soil). The soil has a low supply of mobile phosphorus (8.09 mg P2O5 /100 g soil) and available potassium (14.35 mg K2O /100 g soil). Haplic vertisol is characterized by a close to neutral soil reaction in the plowed layer (pHH2O - 6,4, pHKCl - 5.6), with a high content of total (0,217%) and mineral nitrogen (40,32 mg N/kg soil). The soil has a low supply of mobile phosphorus (1,92 мg P2O5/100 g soil) and better available potassium content (30,86 mg K2O /100 g soil).

Before sowing the seeds, fertilizers with different amounts of active substances in mg/pot were added to the experimental containers of 3 kg capacity, as presented in Table 1. Five sunflower seeds were sown, leaving 3 plants in each pot at a later stage. On the 67-th day of vegetation in the budding phase, the plants were harvested, weighed, and prepared for chemical analysis. The content (% a. d.w.) of macronutrients N, P, K, Si, Ca, and Mg in sunflower plant biomass was determined by acid digestion and ICP readings (5800 ICP - OES system - Agilent). The export of the tested elements with the plant production was determined.

The experiment included 16 fertilization treatments in 3 replications. It is a multifactorial scheme with four factors varied at 5 levels (Sadovski A., 2020). Table 1 shows the experimental design and the imported amounts of the active substance of the macroelements used in mg/pot.

Table 1. Scheme of a pot experiment and quantities of active substance in mg/pot:

1. $N_0P_0K_0Si_0$ - Control	9. $N_{200}P_{160}K_{140}Si_{2000}$
2. $N_0P_{160}K_{140}Si_{800}$	10. $N_{200}P_{160}K_{140}Si_{800}$
3. $N_{400}P_{160}K_{140}Si_{800}$	11. $N_{300}P_{240}K_{70}Si_{400}$
4. $N_{200}P_0K_{140}Si_{800}$	12. $N_{300}P_{80}K_{210}Si_{400}$
5. $N_{200}P_{320}K_{140}Si_{800}$	13. $N_{300}P_{80}K_{70}Si_{1200}$
6. $N_{200}P_{160}K_0Si_{800}$	14. $N_{100}P_{240}K_{210}Si_{400}$
7. $N_{200}P_{160}K_{280}Si_{800}$	15. $N_{100}P_{240}K_{70}Si_{1200}$
8. $N_{200}P_{160}K_{140}Si_0$	16. $N_{100}P_{80}K_{210}Si_{1200}$

The following soil analyses were performed before and after the vegetation experiments: pH - potentiometric in H_2O and KCl (Arinushkina, 1962); total and mineral nitrogen content - Bremner and Kinney method (Bremner, 1965a; Bremner, 1965b); mobile forms of phosphorus and potassium (P_2O_5 и K_2O) - by the acetate-lactate method (Ivanov, 1986); organic carbon (humus) content - according to Turin's method (Kononova, 1963). Statistical analysis of the obtained results was done with Statgraphics statistical product (ANOVA).

Table 2. Dry mater (g/pot) and uptake by sunflower (кg/da) from Tsalapitsa

Variant	Dry matter	N	P	К	Si	Ca	Mg
1	23.717	6.33	1.64	9.89	0.79	0.92	2.35
2	54.947	24.40	6.92	30.17	4.42	23.41	8.90
3	45.601	33.38	7.25	29.00	4.17	27.63	6.43
4	50.118	37.44	5.26	35.93	5.19	30.52	9.92
5	30.086	19.41	5.69	19.04	3.17	18.23	5.33
6	39.475	36.83	6.87	23.45	4.43	25.70	8.88
7	38.295	25.96	6.09	29.07	3.66	21.94	6.89
8	48.331	46.69	8.26	34.51	5.83	33.35	11.02
9	45.864	34.54	6.74	25.59	13.43	26.42	6.88
10	36.771	31.11	5.74	22.06	4.10	23.17	7.83
11	40.320	29.76	7.26	22.98	5.66	26.25	8.71
12	49.003	36.16	5.73	26.76	6.82	24.40	5.88
13	41.816	37.51	6.40	24.84	11.74	23.71	5.52
14	41.312	27.14	6.07	28.01	3.62	20.70	6.82
15	48.131	29.46	7.94	29.17	11.91	25.56	7.94
16	44.072	29.62	5.55	29.88	1.45	23.40	6.21

Table 3. Dry mater (g/pot) and uptake by sunflower (кg/da) from Bozhurishte

Variant	Dry matter	N	P	K	Si	Ca	Mg
1	10.97	5.50	0.86	6.45	0.40	5.86	1.18
2	21.09	6.33	1.46	11.83	1.90	10.82	2.15
3	41.66	24.12	3.62	21.00	8.80	24.50	8.62
4	28.87	24.60	2.08	18.54	3.00	16.72	5.20
5	46.20	28.42	3.74	14.83	3.20	17.33	5.96
6	41.61	33.08	3.62	20.10	6.40	23.09	7.49
7	38.34	23.23	2.99	20.70	3.00	1.84	5.75
8	34.47	18.92	2.69	16.44	2.70	16.65	6.82
9	37.12	18.82	2.67	17.04	11.50	18.93	6.68
10	40.17	19.28	3.13	18.08	3.50	21.21	7.35
11	42.99	37.01	3.87	19.60	3.90	22.70	9.93
12	44.97	31.43	3.10	25.77	4.30	25.90	8.50
13	40.62	27.42	2.32	18.28	3.20	19.74	8.17
14	29.97	15.91	2.43	18.07	3.30	16.09	4.68
15	42.04	18.54	3.53	21.94	3.50	21.06	6.43
16	31.65	17.38	1.99	14.24	2.00	11.49	3.51

Conclusion

In Alluvial-meadow soil as a result of the one-way variance analysis, the data obtained for the amount of plant biomass on the 67th day established the leading role of the nitrogen rate of 200 mg per pot and silicon at 800 mg per pot. The largest biomass was reported in variant B4 ($N_{200}P_0K_{140}Si_{800}$) from the beginning of the experiment and the best plant development was in variants B4 ($N_{200}P_0K_{140}Si_{800}$) and B12 ($N_{300}P_{80}K_{210}Si_{400}$) on day 67. So these combinations of fertilizers are optimal for plant nutrition. At the same time in Haplic vertisol, the leading role of nitrogen fertilization with high norms of 200, 300, and 400 mg/pot and silicon 800 mg/pot was established as a result of the experiment carried out in a vegetation house and from the single-factor dispersion analysis of the values for the amount of biomass of sunflower plants on the 67th day, (the proven difference between variants is at a high confidence level $P \leq 0.001$). Nitrogen is a major nutrient that determines the growth of oilseed crops and increases the amount of protein and yield. Biomass accumulation in sunflower is related to nutrient uptake throughout the growing season (Hassan F. & Kaleem S., 2014).

It is established that the changes in the macroelements uptake significantly follow changes in the quantities of the relevant elements in dry biomass in the variants of the experiment. With an increase in fertilization norms, not only the content of N, P, and Si is increased, but also the uptakes with sunflower biomass. This trend is expressed to a lesser extent with potassium.

There is only a very slight tendency to increase the phosphorus content in the plants with increasing fertilizer rate in Haplic vertisol. Changes in exports of the macroelements examined have been found to follow changes in the quantities of the relevant elements in dry biomass in the variants of the experiment.

Si content increases from 0.0111% in the control variant to 0.0976% in the variant with the highest Si rate. This tendency is similar for both soil types. The combinations of norms and fertilizers used in the experiment do not establish a direct relationship between increasing the accumulation of Si in plants with increasing the imported Si level.

The calcium content is high and ranges from 1.21 to 1.96% but it is significantly higher in the fertilized variants in Haplic vertisol. The content of Ca is very low - 0.13% in the control variant of Alluvial meadow soil but is significantly higher in the fertilizer variants from 1.66 to 2.30% and it cannot be said categorically that higher fertilization rates lead to higher accumulation of Ca in sunflower plants.

The change in the content of Mg varies similarly in both soil types, respectively 0.33 and 0.36% in the control, and in the fertilized variants it is between 0.44 and 0.76% (in Alluvial meadow soil) and between 0.37 and 0.77% (in Haplic vertisol). Applied fertilization has a significantly lower effect on the accumulation of Mg in sunflower plants.

To sum up, the leading role of nitrogen is evident but in order to improve agricultural production and soil fertility there is a need to optimize the nutrient regime of plants.

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References:

Ahmad, I., Jadoon, S. A., Said, A., Adnan, M., Mohammad, F., & Munsif, F. (2017). Response of sunflower varieties to NPK fertilization. Pure and Applied Biology (PAB), 6(1), 272-277.

Bremner, J.M. (1965a). Organic Nitrogen in Soils, Agron. J., 10, 93-149.

Bremner, J.M. (1965b). Inorganic forms of Nitrogen. In: C.A. Black et al., /Eds./. Methods of Soil Analyses. Part 2: Chemical and Microbiological Properties. № 9, Agronomy. American Society of Agronomy Inc. Madison, Wisconsin, USA, pp. 1179-1237.

Hassan, F.U., Kaleem, S. (2014). Influence of seasonal disparity on NPK uptake in sunflower. The Journal of Animal & Plant Sciences, 24(1), 190-196.

Ivanov, P. (1986). New Acetate-lactate Method for Determination of Available Forms of P and K in Soil. Soil Science and Agrochemistry, 19 (4), 88-98.

Koinov, V. (1987). Correlation between the soils of Bulgaria and the soils distinguished by the major soil classification systems in the world. Soil Science, Agrochemistry and Plant Protection, 22(5), pp. 5-13 (Bg)

Kononova, M.M. (1963). Soil organic matter. Its nature, properties and methods of study. M., AN SSSR, 314 p.

Nenova, L., Mitova, V. (2018). Content and uptake of macroelements with the production of cabbage. Soil Science Agrochemistry and Ecology, 52, 3, 34-42. (Bg)

Nikolova, M. (2010). Potassium - a nutrient for yield and quality. International Potash Institute, Horgen-Switzerland, p.50-52.

Pavlovic, J., Kostic, L., Bosnic, P., Kirkby, E.A., Nikolic, M. (2021). Interactions of silicon with essential and beneficial elements in plants. Frontiers in Plant Science, 12, 1224.

Peixoto, Murilo de Melo., Rilner Alves Flores, Charlismilã Amorim do Couto, Haryel Domingos N. Pacheco, Renato de Mello Prado, Jonas Pereira Souza-Junior, José Arnaldo Castro-Netto & Dalva Graciano-Ribeiro. (2022). Silicon Application Increases Biomass Yield in Sunflower by Improving the Photosynthesizing Leaf Area. Silicon, volume 14, pages 275–280.

Sadovski, A. (2020). An Introduction to Mathematical Agronomy: Theoretical and Experimental bases. LAP Lambert Academic Publishing. ISBN 978-620-2-51889-5, 284 pp.

Zichuan Li, Zhaoliang Song, Zhifeng Yan, Qian Hao, Alin Song, Linan Liu, Xiaomin Yang, Shaopan Xia & Yongchao Liang. (2018). Silicon enhancement of estimated plant biomass carbon accumulation under abiotic and biotic stresses. A meta-analysis. Agronomy for Sustainable Development, volume 38, Article number: 26.

Enhancing Biomass and Phycocyanin Productivity of *Spirulina* sp. Cultivated in Anaerobically Digested Brewery Effluent

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ABSTRACT

Breweries are significant contributors to wastewater and CO_2 generation. To address this environmental concern, microalgae-based biological water treatment has emerged as an eco-friendly solution that simultaneously sequesters CO_2 and treats wastewater. Furthermore, the biomass generated through this process can be utilized for value-added purposes. This study aims to explore the potential of blue-green microalgae, specifically *Spirulina* sp., for wastewater treatment and the production of high-value products without the need for a drying step. Our objectives were to treat wastewater, extract phycocyanin and fatty acids, and utilize the residual biomass for anaerobic digestion to produce biogas. Initially, the performance of *Spirulina* sp. was optimized by analyzing the growth, pigment, and fatty acid profile of cultures cultivated under various LED light colors (blue, red, purple, and white) and CO_2 concentrations (air, 5%, 10%, and 15% CO_2). The biomass grown under the optimal conditions was then used for subsequent valorization steps. For the optimization experiments, triplicate cultures with a 10% inoculum were prepared by mixing 150 mL of stock culture (standardized at OD_{750} = 0.02), grown under ambient conditions, with 1350 mL of aerobically digested effluent from a brewery, in vertical tubular reactors. Aeration was provided from the bottom of the reactors at a flow rate of 1000 mL/min to ensure sufficient air supply and culture mixing. LED lights were employed to establish a 12-12 dark-light cycle with a light intensity of 50 µmol/m^2/s. The results indicated that red light stimulated the highest growth and biomass productivity. Moreover, the initial screening revealed that a 10% CO_2 concentration significantly enhanced biomass productivity. Additionally, variations in both CO_2 concentration and LED colors influenced the accumulation of pigments and the fatty acid profile of the studied *Spirulina* sp. Furthermore, the biochemical methane potential (BMP) was optimized by adjusting the substrate-to-inoculum ratio (S/I) to optimize the anaerobic digestion of pigment and lipid-free biomass. This study demonstrates the potential for optimizing the performance of *Spirulina* sp. in wastewater treatment and biomass valorization through the manipulation of LED light colors and CO_2 concentrations. These findings contribute to the development of sustainable and efficient strategies for wastewater treatment in the brewery industry while exploring the production of valuable bioactive compounds from microalgae biomass.

BIOFILM - SUPPORTING DENITRIFICATION AND DEPHOSPHATATION WITH CITRIC ACID

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Keywords: biofilm; drainage water; citric acid; denitrification; dephosphatation

ABSTRACT

Introduction

Water is a strategic global resource, and demand for it is successfully growing. Increasingly often, the volumes of water used exceed the capacity of its natural supplementation. This overuse causes the lowering of the groundwater level and depletion of available freshwater resources [1]. Agriculture is one of the main sectors of economy featuring high consumption of freshwater resources. At the same time, climate warming and rising temperatures will more and more often require the use of irrigation systems in agriculture. The leaching or discharge of agriculture-derived nutrients into waters or soil severely deteriorate the natural environment condition [2]. For this reason, solutions should be sought to ensure effective removal of nutrients from drainage waters (DW). One of such solutions may be various types of solutions based on biomass attached to the fill. The tests carried out were aimed at determining the possibility of denitrification and biological dephosphatation in a system based on a biofilm. In order to support the purification processes, an external source of organic carbon in the form of citric acid was used. This substrate is characterized by a low increase in excess biomass [3]. This reduces the loading of the fill with biomass and clogging of the bed.

Methods

A biological reactor with a filling in the form of discs with a biofilm was used in the research. The ratio of the surface of the shields to the volume of the reactor was 45 m^2/m^3. The reactor filling was rotated at a speed of 14 rpm. The construction of the reactor enabled periodic filling and discharge of the entire volume of DW along with excess biomass. The hydraulic retention time of DW was 12 hours. The reactor was operated at 20-22°C. Drainage waters with a high content of biogenic compounds and a low content of organic compounds (COD 20 mg/L; nitrates 70 mgN/L; orthophosphates 7 mgP/L) was used in the study. As the only source of organic carbon, citric acid was used in 4 doses, providing from 50% to 125% of the microorganisms' demand for denitrification and biological dephosphatation [4]. This corresponded to a test run with an initial concentration of organic compounds of 212.0 mgCOD/L (series 1); 404.0 mgCOD/L (series 2); 596.0 mgCOD/L (series 3) and 788.0 mgCOD/L (series 4).

Results

Solutions based on a biofilm are characterized by high operational reliability, resistance to changes in the supplied load of pollutants, changes in the physicochemical parameters of wastewater, such as pH, salinity and the presence of toxic substances. At the same time, the biofilm is characterized by a small amount of excess biomass discharged from the reactor, which must be managed. One way to increase the efficiency of denitrification and biological dephosphatation is to use an external source of organic carbon. Citric acid was used in the studies. Easily accessible substrate, convenient and safe to store and transport. Produced on an industrial scale. The highest efficiency of phosphorus removal amounting to 43.6±3.8% was obtained at the initial concentration of organic substrate 788.0 mgCOD/L, the lowest 22.5±4.6% at the lowest dose of organic substrate. This corresponded to the amount of biomass discharged from the reactor, respectively 104.2±36.7 mg d.m./L (series 4) and 18.3±13.6 mg d.m./L (series 1). The initial concentration of organic compounds in series 2-4 allowed for high denitrification efficiency ranging from 98.7±0.3 to

98.6±0.1%, respectively. The lowest denitrification efficiency was recorded at the lowest dose of citric acid and amounted to 41.5±4.0%. This corresponded to an effluent nitrogen concentration of 41.0±2.8 mgN/L.

Conclusion

Citric acid is an unconventional source of organic carbon in biological treatment processes. However, it has many advantages over the commonly used methanol or acetate. At the same time, the studies carried out indicate that it has good properties to support the biological removal of nitrogen and phosphorus through the biological membrane. This can be used in various types of systems based on biomass attached to the fill.

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References:

1. Garcia-Caparros, P.; Contreras, J.I.; Baeza, R.; Segura, M.L.; Lao, M.T. Integral Management of Irrigation Water in Intensive Horticultural Systems of Almería. *Sustainability (Switzerland)* 2017, *9*, 2271.

2. Mielcarek, A.; Rodziewicz, J.; Janczukowicz, W.; Dobrowolski, A. Analysis of Wastewater Generated in Greenhouse Soilless Tomato Cultivation in Central Europe. *Water (Basel)* **2019**, *11*, 2538, doi:10.3390/w11122538.

3. Mielcarek, A.; Rodziewicz, J.; Janczukowicz, W.; Dabrowska, D.; Ciesielski, S.; Thornton, A.; Struk-Sokołowska, J. Citric Acid Application for Denitrification Process Support in Biofilm Reactor. *Chemosphere* **2017**, *171*, 512–519, doi:10.1016/J.CHEMOSPHERE.2016.12.099.

4. Grady, L.C.P.JR.; Daigger, G.T.; Lim, H. *Biological Wastewater Treatment*; 2nd ed.; Marcel Decker: Basel. Switzerland, 1999;

Dynamic electricity price: challenge for selection of cost-optimal PV Systems for households

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ABSTRACT

Empowering citizen energy communities (CEC) to produce, self-consume and sharing renewable energy can help improve household energy efficiency, support the use of renewable energy, and at the same time can reduce energy consumption and supply tariffs, as well as increase Latvia's independence from fossil fuel supplying countries. The study analyzes actual collected electricity consumption data of 31 dwellings of typical five-story multiapartment buildings in Riga (Latvia), with the possibility of installing rooftop solar energy-based generation systems for CEC organization. We evaluate a Latvian typical building stock for rooftop photovoltaics (PV) systems. The aim of the analysis is to determine the possible PV performance to the final electricity consumption. For the study was selected PolySun computer simulation software. Theoretically about 800 typical five-story multiapartment building will be possible to participate as a CECs in Riga. It was found out that rooftop PV system placed on typical multipayment building can cover up to 77 % of consumed electricity annually. The performed analysis was based on hourly data on real electricity consumption. Research outcomes could be used to optimized on-side energy storage to reduce impact of PV system on grid.

Remote Sensing Analysis for Vegetation Assessment of a Large-Scale Constructed Wetland Treating Produced Water Polluted with Oil Hydrocarbons

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Keywords: Constructed Wetlands; Produced Water; Remote Sensing; ERDAS; NDVI; MSAVI; NDSI.

ABSTRACT

Identification and assessment of plant stress out of wetland satellite images is a major task in remote sensing. In this study, one of the largest constructed wetlands (CW) in the world, located in the Sultanate of Oman, was examined, assessed, and evaluated using remote sensors data of Sentinel-2. This CW system is treating produced water generated during the oil exploration activities in a desert environment; thus, CW vegetation is subjected to a stress induced by oil hydrocarbons and water salinity. The study examined the plant stress and detected changes between the years 2017 and 2019. Sentinel satellite images were evaluated for vegetation status extraction. The Normalized Difference Vegetation Index (NDVI), Modified Soil Adjusted Vegetation Index (MSAVI), and Normalized Difference Salinity Index (NDSI) were used to evaluate the vegetation change. The results showed a comprehensive mapping identification of plant stress and water flow parameters factors including Oil in Water Contamination (OIW), Dissolved Oxygen (DO), Water Temperature WT), and Water Conductivity (COND). Among the three indices, it was found that NDVI showed a very good correlation with all parameters in both years with average R2 = 0.78, 0.67, 0.75, and 0.60 for OIW, DO, WT, and COND, respectively. Same trend was found for MSAVI but with R2 = 0.59, 0.48, 0.55, and 0.56 for OIW, DO, WT, and COND, respectively. Showing that NDVI did better job than MSAVI in evaluating the water flow parameters. On other hand, NDSI showed a strong correlation one flow parameter that is water conductivity especially at the outlet cells of the CW with R2 = 0.86 and 0.82 for winter and summer times, respectively. Mapping of such a critical and massive industrial CW should consider the use of high spatial resolution sensors where identifications and classifications are further improved. The synchronization and correlation between water flow parameters and remote sensing vegetation indices in this study leads to a new approach to large-scale landscape wetland monitoring that improves and helps predict any degradation or stress on vegetation growth. Furthermore, the results of this work help the decision-makers in potentially modifying the wetland design and water flow path to improve the future expansion phases. Overall, this study provides the results of this study indicate that it is possible to generate an estimation of the CW vegetations stress with remote sensing technique over large areas if sufficient field data, satellite imagery, and ancillary data are available.

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Greenhouse gas emissions from Lumnitzera racemosa mangroves

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Keywords: CO_2, CH_4, N_2O, stem, soil

ABSTRACT

Over the past decades, mangroves have been greatly declined due to human development and are still disappearing. Mangrove forests are important blue carbon ecosystems that not only serve for biodiversity conservation, protection of coastal soil erosion, and reduction of floods, but also possess a high ability of carbon sequestration to mitigate climate change. However, due to the respiration of soil microorganisms and plants in the mangrove forests, they are also sources of greenhouse gas (GHG) emissions. Previous studies have shown that greenhouse gas emissions from mangrove forests may offset their carbon burial rate. Inconsistent with most mangroves living in coastal waters, Lumnitzera racemosa mangroves can grow both in coastal waters and terrestrial environments. However, the GHG emission from L. racemosa mangroves is little known. This study measured GHG emissions from the stems and soils of the L. racemosa mangroves in Taiwan in 2023. The results showed that the stems of the L. racemosa emitted carbon dioxide (CO_2) (terrestrial: 0.52 ± 0.24 *mmol* $m^{-2}\ h^{-1}$; water: 0.64 ± 0.91 *mmol* $m^{-2}\ h^{-1}$), methane (CH_4) (terrestrial: 0.01 ± 0.04 *μmol* $m^{-2}\ h^{-1}$; water: 0.62 ± 1.02 *μmol* $m^{-2}\ h^{-1}$), and nitrous oxide (N_2O) (terrestrial: $5.04 \times 10^{-3} \pm 8.12 \times 10^{-3}$ *μmol* $m^{-2}\ h^{-1}$; water: $-7.73 \times 10^{-4} \pm 1.03 \times 10^{-2}$ *μmol* $m^{-2}\ h^{-1}$). CO_2 (terrestrial: 3.85 ± 4.98 *mmol* $m^{-2}\ h^{-1}$; water: 1426.00 ± 1156.69 *mmol* $m^{-2}\ h^{-1}$), CH_4 (terrestrial: -0.17 ± 0.45 *μmol* $m^{-2}\ h^{-1}$; water: 544.22 ± 602.19 *μmol* $m^{-2}\ h^{-1}$), and N_2O (terrestrial: 0.01 ± 0.06 *μmol* $m^{-2}\ h^{-1}$; water: 44.21 ± 47.19 *μmol* $m^{-2}\ h^{-1}$) emissions from the soils were also recorded. The GHG emissions were significantly higher in the water than in the terrestrial mangroves. The GHG emissions were also significantly higher from the soils than the stems. In the future, we will continue to examine the GHG emissions from the soils and stems of L. racemosa in different seasons.

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Establishment of carbon sink coefficients of seagrasses in tropical islands

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Keywords: Seagrasses, Carbon Sink, *Halophila ovalis*, *Halodule uninervis*

ABSTRACT

Blue carbon ecosystems, including mangroves, salt marshes, and seagrass meadows, are important transition areas connecting land, freshwater, and the ocean, providing and supporting many ecosystem services. In addition, blue carbon ecosystems have high productivity since a great amount of litter and roots accumulate and bury in the soil, forming a considerable carbon stock. The seagrass areas are also the largest among the three major coastal blue carbon ecosystems in Taiwan. This study investigated the variations of carbon sink in seagrass ecosystems in the Penghu Islands in the winter (January) and spring (April) in 2023 and established carbon sink measurement methodology, carbon sink coefficient, and carbon sink baseline data in the seagrass ecosystems. Four research stations, including Citou (CT1 and CT2), Zhenhai (ZH), and Jiangmei (JM) were established. Halophila ovalis dominate CT1, while CT2, JM and ZH are dominated by Halodule uninervis. The results indicated that the productivity of Halodule uninervis is about 40 times higher than that of Halophila ovalis. The seagrass coverage varies greatly between the two seasons. The highest coverage is ZH (47.25±17.77 %), followed by JM and CT2 (44.02±18.24 % and 43.19±15.86 %), and CT1 is the lowest (37.77±23.06 %) in winter. The highest coverage was CT2 (41.38±8.8 %), followed by CT1 and JM (36.93±17.79 % and 35.81±25.72 %), and ZH was the lowest (29.87±20.11 %) in spring. The daily carbon sequestration capacity of leaves was converted into daily carbon sequestration capacity. The results showed that the highest capacity was Halodule uninervis in CT2 and ZH (20.11 and 18.75 kg C DW d^{-1}), followed by JM (0.83 kg C DW d^{-1}). The lowest capacity was Halophila ovalis in CT1 (0.14 kg C DW d^{-1}).

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BIOETHANOL PRODUCTION FROM MICROWAVE-ASSISTED DEEP EUTECTIC SOLVENT PRETREATED WHEAT STRAW

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Keywords: wheat straw, deep eutectic solvent, microwave, pretreatment, bioethanol

ABSTRACT

Economic stability and national security issues are tightly linked to energy supply security. The increasing oil consumption causes not only environmental problems and contributes to global climate change but also influences national security issues. Therefore, it is necessary to replace fossil fuels by domestic renewable and sustainable sources of energy. Lignocellulosic material such as agricultural residues (e.g. straw) are widely available and can be used for the production of biofuels. In this study, it was aimed to investigate the effect of microwave assisted deep eutectic solvent pretreatment (MW-DES) on bioconversion of wheat straw. The samples were treated with DES (choline chloride: formic acid) at various mole ratios (1:2, 1:3, and 1:4), microwave power (270, 360, and 450 W) and pretreatment time (2, 5, and 8 min). Xylan was found to be the most affected constituent of biomass during MW-DES. At severe pretreatment conditions, 90 % of the xylan was solubilized. Highly digestible and fermentable wheat straw fibers were obtained after the removal of hemicellulose and lignin fraction. The pretreated solid fraction was subjected to enzymatic hydrolysis experiments and it was observed that MW-DES was vastly effective at achieving very high sugar yields (99 % glucose, 85 % xylose yield). The process conditions that provided the maximum total sugar (619 mg/g pretreated wheat straw fibers) release during enzymatic hydrolysis were selected as the optimal conditions (1 : 3 mole ratio, 360 W microwave power, and 8 min pretreatment time). The wheat straw samples that were pretreated at the optimal conditions were also simultaneously saccharified and co-fermented using Cellic Ctec2 and E. coli KO11 (ATCC 55124). The theoretical ethanol yield was 81.5 %.

Deep Eutectic Solvent Pretreatment of Olive Pomace

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Keywords: Lignocellulosic material, olive pomace, deep eutectic solvent, pretreatment, phenolics, carbohydrates

ABSTRACT

Olive, which has an important economic value, has been grown in the Mediterranean basin since ancient times and has a very important place in the cultures of civilizations established in this region (Eskiyörük 2016). Olive oil is one of the main components of the Mediterranean diet and has high nutritional value (Borello and Domenici 2019). Olive pomace (OP) obtained as a by-product of olive oil processing is a lignocellulosic waste characterized by its low nutritional value, high fiber, and phenolic content (Valta et al. 2015; Filipe et al. 2020). Globally, 20-30 million tons of OP is produced annually which could be utilized to produce value added products.

Lignocellulosic materials are generally consisting of cellulose (35-50%), hemicellulose (20-35%) and lignin (15-25%) (Sharma et al. 2022). The lignin component protects the cellulosic structure from enzymatic hydrolysis, microbial degradation etc. (Singhania et al. 2022; Nargotra et al. 2022). Hence, it is vital to break down the lignocellulosic structure prior to any conversion processes. The pretreatment process causes structural and compositional changes in lignocellulosic biomass by removing lignin/hemicellulose fraction. Even though different kinds of pretreatment methods were studied using olive pomace such as alkali, dilute acid, liquid hot water, and steam explosion (Gómez-Cruz et al. 2022, Manzanares et al. 2020, Elalami et al. 2020, Seçmeler et al. 2018, Pellera et al. 2016, Kazan et al. 2015), environmentally friendly processes are still under search.

Deep eutectic solvents (DES) are attracting great attention due to its excellent capacity to dissolve lignin in lignocellulosic biomass, low synthesis cost, recyclability, and environmentally friendly properties (Zhou et al. 2022). It has been reported that different lignocellulosic materials such as wheat straw (Zhao et al. 2018), miscanthus (Hassan and Mutelet 2022), rice straw (Zhao et al. 2018), corn stover (Xu et al. 2016) were effectively pretreated using DES. Therefore, the main objective of this study was to investigate the effect of DES pretreatment on OP. The treatment was carried out using DES (choline chloride and formic acid (1:2 molar ratio)) at different temperatures (90, 110 and 130 °C) and treatment times (20, 40 and 60 min) at a solid to solvent ratio of 1:10 (g/mL). The percentage of solids recovered during the pretreatment was in the range of 53.56 - 79.08%. It was observed that more solids were solubilized at higher temperatures and longer pretreatment times. The highest total phenolic content (75.6 mg GAE / g dry OP) was observed at 130°C-60 min. The effect of process conditions on the different sugar yields were also analyzed using a Dionex ICS-6000 system (Thermo Scientific, USA) with pulsed Amperometric detection (HPAEC–PAD). Sugar release was also increased at severe pretreatment conditions. The liquid fraction contained mostly xylose and minor amount of glucose and arabinose. The concentrations of xylose, glucose and arabinose were 1.6, 0.99 and 0.82 g/L at 130°C-60 min, respectively.

References

Borello, E. and Domenici, V. 2019. Determination of pigments in virgin and extra-virgin olive oils: A comparison between two near UV-vis spectroscopic techniques. Foods, 8(1), 18. https://doi.org/10.3390/foods8010018.

Elalami, D., Carrere, H., Abdelouahdi, K., Garcia-Bernet, D., Peydecastaing, J., Vaca-Medina, G. and Barakat, A. 2020. Mild microwaves, ultrasonic and alkaline pretreatments for improving methane production: Impact on biochemical and structural properties of olive pomace. Bioresource technology, 299, 122591. https://doi.org/10.1016/j.biortech.2019.122591.

Eskiyörük, D. 2016. Olive and olive oil in ancient times: An example from the Cilicia Region. Journal of Tourism & Gastronomy Studies, 4, 228-243.

Filipe, D., Fernandes, H., Castro, C., Peres, H., Oliva-Teles, A., Belo, I. and Salgado, J. M. 2020. Improved lignocellulolytic enzyme production and antioxidant extraction using solid-state fermentation of olive pomace mixed with winery waste. Biofuels, Bioproducts and Biorefining, 14(1), 78-91. https://doi.org/10.1002/bbb.2073.

Gómez-Cruz, I., Romero, I., Contreras, M. D. M., Labidi, J., Hernández-Ramos, F., Roseiro, L. B. and Carvalheiro, F. 2022. Combined extraction and ethanol organosolv fractionation of exhausted olive pomace for bioactive compounds. Advanced Sustainable Systems, 6(4), 2100361. DOI: 10.1002/adsu.20210036.

Hassan, E. S. R. and Mutelet, F. 2022. Evaluation of miscanthus pretreatment effect by Choline chloride based Deep Eutectic solvents on bioethanol production. Bioresource Technology, 345, 126460. https://doi.org/10.1016/j.biortech.2021.126460.

Kazan, A., Celiktas, M. S., Sargin, S. and Yesil-Celiktas, O. 2015. Bio-based fractions by hydrothermal treatment of olive pomace: Process optimization and evaluation. Energy Conversion and Management, 103, 366-373. http://dx.doi.org/10.1016/j.enconman.2015.06.084.

Manzanares, P., Ballesteros, I., Negro, M. J., González, A., Oliva, J. M., Ballesteros, M. 2020. Processing of extracted olive oil pomace residue by hydrothermal or dilute acid pretreatment and enzymatic hydrolysis in a biorefinery context. Renewable Energy, 145, 1235-1245. https://doi.org/10.1016/j.renene.2019.06.120.

Nargotra, P., Sharma, V., Sharma, S., Bangotra, R. and Bajaj, B. K. 2022. Purification of an ionic liquid stable cellulase from Aspergillus aculeatus PN14 with potential for biomass refining. Environmental Sustainability, 5(3), 313-323. https://doi.org/10.1007/s42398-022-00232-x.

Pellera, F. M., Santori, S., Pomi, R., Polettini, A., Gidarakos, E. 2016. Effect of alkaline pretreatment on anaerobic digestion of olive mill solid waste. Waste management, 58, 160-168. http://dx.doi.org/10.1016/j.wasman.2016.08.008.

Seçmeler, Ö., Üstündağ, Ö. G., Fernández-Bolaños, J., Rodríguez-Gutiérrez, G. 2018. Effect of subcritical water and steam explosion pretreatments on the recovery of sterols, phenols and oil from olive pomace. Food chemistry, 265, 298-307. https://doi.org/10.1016/j.foodchem.2018.05.088.

Sharma, V., Tsai, M. L., Chen, C. W., Sun, P. P., Patel, A. K., Singhania, R. R. and Dong, C. D. 2022. Deep eutectic solvents as promising pretreatment agents for sustainable lignocellulosic biorefineries: A review. Bioresource Technology, 127631. https://doi.org/10.1016/j.biortech.2022.127631.

Singhania, R. R., Patel, A. K., Raj, T., Chen, C. W., Ponnusamy, V. K., Tahir, N. and Dong, C. D. 2022. Lignin valorisation via enzymes: A sustainable approach. Fuel, 311, 122608. https://doi.org/10.1016/j.fuel.2021.122608.

Valta, K., Aggeli, E., Papadaskalopoulou, C., Panaretou, V., Sotiropoulos, A., Malamis, D. and Haralambous, K. J. 2015. Adding value to olive oil production through waste and wastewater treatment and valorisation: the case of Greece. Waste and biomass valorization, 6, 913-925. DOI 10.1007/s12649-015-9373-4.

Xu, G. C., Ding, J. C., Han, R. Z., Dong, J. J. and Ni, Y. 2016. Enhancing cellulose accessibility of corn stover by deep eutectic solvent pretreatment for butanol fermentation. Bioresource technology, 203, 364-369. https://doi.org/10.1016/j.biortech.2015.11.002.

Zhao, Z., Chen, X., Ali, M. F., Abdeltawab, A. A., Yakout, S. M. and Yu, G. 2018. Pretreatment of wheat straw using basic ethanolamine-based deep eutectic solvents for improving enzymatic hydrolysis. Bioresource technology, 263, 325-333. https://doi.org/10.1016/j.biortech.2018.05.016.

Zhou, M., Fakayode, O. A., Yagoub, A. E. A., Ji, Q. and Zhou, C. 2022. Lignin fractionation from lignocellulosic biomass using deep eutectic solvents and its valorization. Renewable and Sustainable Energy Reviews, 156, 111986. https://doi.org/10.1016/j.rser.2021.111986.

Can landraces better cope with environmental stress?

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ABSTRACT

Plants, being sessile organisms, have to endure a complex mixture of environmental stresses. One of the major factors influencing the survival, behaviour and performance of plants is drought. In Europe, increased frequency of droughts in the past two decades has been reported (Hari et al. 2020), seriously affecting agriculture (Crocetti et al. 2020). There are evidences that lack of appropriate water supply can have significant effects on the biochemical and physiological processes of the plants which will ultimately result in reduced growth and yield (Sharma et al. 2019).

Agricultural fields or gardens are often found in the vicinity of roads being also influenced by air pollution generated by vehicular traffic. Traffic-related emissions contain both gaseous and particulate pollutants. Particulate matter (PM) might bind potentially toxic chemicals such as polycyclic aromatic hydrocarbons or heavy metals. They exert toxic effects mainly by triggering reactive oxygen species (ROS) production (Gao et al. 2020).

However, some crop varieties might show better tolerance to combined stress, and selection of proper crop varieties can be especially important to mitigate the effects of climate change (Bindi and Olesen 2011). As such, the major objective of the study presented here was to evaluate the combined effect of air pollution and drought stress comparing the sensitivity of different tomato varieties vs. landraces. Tomato (*Lycopersicon esculentum* Mill.) was selected as the test species being one of the most widely cultivated vegetables, showing also good sensitivity to air pollutants (Hubai et al. 2021).

For the study, three different varieties/landraces have been chosen. 'Roma' is a commercially available variety which has been used in previous studies (Daresta et al. 2015). 'Gulácsi' and 'Tápószelei' are regional landraces, seeds were provided by the Gene Bank of Tápószele (Hungary).

In order to test the combined effects of atmospheric particulate pollution and drought, 4 test groups (TG) of each variety were used as follows:

TG1 (Control)	**TG2**	**TG3**	**TG4**
Drought stress: No **Chemical stress: No**	Drought stress: Yes Chemical stress: No	Drought stress: No Chemical stress: Yes	Drought stress: Yes Chemical stress: Yes

In order to simulate airborne particulate matter related chemical stress, aqueous extract of diesel exhaust was prepared and test plants were sprayed with the extract simulating atmospheric wet deposition. This treatment is in complience with the No. 227 OECD GUIDELINE FOR THE TESTING OF CHEMICALS: Terrestrial Plant Test: Vegetative Vigour Test. Deleterious effects were assessed after 3 weeks exposure based on biomass (growth inhibition), photosynthetic pigments (Chlorophyll-a, Chl-b, Carotene) and the stress enzyme peroxidase.

Preliminary results indicate the higher resistance of landraces toward abiotic stress, 'Gulácsi' showing the best adaptation. These data are in concordance with the literature as most of the commercial cultivars investigated have been found more drought sensitive (Zdravkovic et al. 2013). The study highlights the importance of careful selection of landraces in order to cope with environmental stress in a changing climate and also to make a step towards a sustainable agriculture.

References

1. Bindi M, Olesen JE (2011) The responses of agriculture in Europe to climate change. Regional Environmental Change 11 (Suppl 1):S151–S158
2. Crocetti L, Forkel M, Fischer M, Jurečka F, Grlj A et al. (2020) Earth Observation for agricultural drought monitoring in the Pannonian Basin (southeastern Europe): current state and future directions. Regional Environmental Change 20: 123
3. Daresta BE, Italiano F, de Gennaro G, Trotta M, Tutino M, Veronico P (2015) Atmospheric particulate matter (PM) effect on the growth of *Solanum lycopersicum* cv. Roma plants. Chemosphere 119:37–42.
4. Gao D, Ripley S, Weichenthal S, Pollitt KJG (2020) Ambient particulate matter oxidative potential: Chemical determinants, associated health effects, and strategies for risk management. Free Radical Biology and Medicine 151: 7–25
5. Hari V, Rakovec O, Markonis Y, Hanel M, Kumar R (2020) Increased future occurrences of the exceptional 2018–2019 Central European drought under global warming. Scientific Reports 10:12207
6. Hubai K, Kováts N, Teke G (2021) Effects of urban atmospheric particulate matter on higher plants using *Lycopersicon esculentum* as model species. SN Applied Sciences 3: 770
7. Sharma S, Leskovar D, Crosby K (2019) Genotypic differences in leaf gas exchange and growth responses to deficit irrigation in reticulatus and inodorus melons (*Cucumis melo* L.). Photosynthetica 57: 237–247 .
8. Zdravkovic J, Jovanovic Z, Djordjevic M, Girek Z, Zdravkovic M, Stikic R (2013) Application of stress susceptibility index for drought tolerance screening of tomato populations. Genetika 45(3): 679-689.

Nature-based coastal protection measures in a circular society

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Keywords: sand nourishment, erosion protection, dune vegetation

ABSTRACT

The concept of a circular society seeks sustainable development by minimizing waste and promoting efficient resource use. In coastal areas, sand nourishments have emerged as a nature-based solution to address coastal erosion while maintaining coastal ecosystems (Pontee et al. 2016; Lammerts et al. 2009). However, their long-term implementation is challenged by uncertainties associated with potential impacts of climate change, particularly sea-level rise and increased storm frequency. As a result, coastal planners and affected communities question the technical feasibility, economic efficiency and ecological viability of these nature-based measures, challenging their political legitimacy and social acceptability.

Sand nourishments involve adding sand to eroded beaches or dunes, utilizing the natural protective functions of coastal ecosystems (Nordstrom et al. 2004). By recognizing the connectivity of these ecosystems, coastal areas can benefit from sustainable sand sourcing and reuse. To understand the ecological impacts of these measures, the following case study was conducted. Both short and long-term effects on aquatic and terrestrial coastal ecosystems were observed during a 24 month's survey that began started in June 2021 in Ahrenshoop at the Baltic Sea (Germany). Sediment structure and vegetation along the nourished beach as well as the turbidity plume caused by the nourishment, were monitored.

It was shown that it takes around 6 months to return to pre-nourishment sediment and water conditions. This is due to the mechanism of the nourishment itself and depends on the sediment being nourished. In this case, the nourished sediment's characteristics were similar to sediment on beach and dune. Organic content decreased as the nourished sediment was organic-poor, but quickly returned to conditions prior to the nourishment. Algal vegetation was only affected by seasons and not affected by the nourishment. In contrast, major changes occurred in dune vegetation as a portion of the dune was buried beneath the nourished sand. Vegetation cover and species diversity in the primary and secondary dunes decreased as both were buried under a new sediment layer, and only *Ammophila arenaria* was restored there, e.g. mean species number decreased from 4.4 ± 1.0 to 3.2 ± 0.4 species after the nourishment on the white dune. Not nourished white dunes showed mean species numbers of 11.8 ± 0.7 species. The tertiary dune was not directly affected by the nourishment as it was not covered by nourished sediment. Nevertheless, comparison of the dune with unnourished dunes showed lower overall species diversity, even for the tertiary dune. Mean species number decreased from 5.8 ± 1.5 to 5.0 ± 2.5 species after the nourishment while unnourished grey dunes showed mean species number of 13.8 ± 5.3 species.

Sand nourishments can alter the ecology of a coastal ecosystem. Even after restoring similar sediment parameters, the case study results indicate that long-term effects on dune vegetation occur. Therefore, in order not to endanger biodiversity in surrounding ecosystems, more resilient dunes need to be created, e.g. through ecological engineering. Possible improvement approaches here include supporting plant nutrient supply through beach wrack and planting dune typical species to allow natural repopulation through biodiversity hotspots. Integrating sand nourishments within the circular society framework can enhance resource efficiency and resilience, fostering a sustainable future for coastlines and the environment.

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References:

Lammerts EJ, Petersen J, Hochkirch A (2009). Beaches and Dunes. Wadden Sea Ecosystems No. 25; Quality Status Report 2009 / Thematic Report No. 15

Nordstrom KF, Jackson NL, Pranzini E (2004). Beach Sediment Alteration by Natural Processes and Human Actions: Elba Island, Italy. Annals of the Association of American Geographers (94 (4)):794–806

Pontee N, Narayan S, Beck MW, Hosking AH (2016). Nature-based solutions: lessons from around the world. Proceedings of the Institution of Civil Engineers - Maritime Engineering 169(1):29–36. doi: 10.1680/jmaen.15.00027

Effect of wheat bran pre-treatment on isolation of ferulic acid

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Keywords: Ferulic acid, wheat bran, biorefinery, alkaline hydrolysis, pretreatment methods

ABSTRACT

Ferulic acid (FA) is a highly valued bioactive substance. It has a significant antioxidant effect, antimicrobial, anticancer, antiallergic, hepatoprotective, anti-inflammatory and antiviral effects. Due to these properties, the use of FA in the food, pharmacological and cosmetic industries is extensive. Recently, significant efforts have been made to find nonchemical processes for the preparation of this substance. One possible way to solve this issue is to valorize waste lignocellulosic materials i.e. from the cereal processing industry (Apprich et al., 2014, Stavova et al., 2017). According to FAOSTAT, the world's processing of wheat produces more than 120 million metric tons of wheat bran (WB), which contain a significant amount of FA. However, in the isolation of FA from wheat bran, pretreatment of the raw material is needed. This step is crucial because it helps to remove unwanted components and enhance the efficiency of the isolation process.

In this study, the effect of different pretreatments of wheat bran before the process of alkaline hydrolysis for the isolation of FA was tested. The pretreatments that were tested included the removal of protein, starch, and a combination of starch and protein removal. The final pretreatment that was tested involved the removal of starch, lipids, and protein.

After the alkaline hydrolysis of native WB, a yield of 1.5 mg/g of FA was obtained. The amount of FA in WB ranges from 1 to 5 mg/g. The effectiveness of alkaline hydrolysis is reported to be between 60% and 90%. Therefore, the yield of 1.5 mg/g FA appears to be realistic and likely the highest possible. However, the content of FA in the obtained hydrolysate was only 0.42%. This result indicates that the hydrolysate contains other components as impurities.

After pretreatment of WB with hot water, a yield of 0.99 mg/g of FA was obtained from subsequent alkaline hydrolysis. This indicates that some FA was lost during the hot water pretreatment. However, it was found that the content of FA in the hydrolysate increased to 0.77%. This suggests that some impurities, likely starch, were removed by the hot water wash. The presence of starch in the hot water after the WB pretreatment was confirmed by an iodine test.

After pretreatment of WB with 0.05M NaOH, a yield of 1.24 mg/g of FA was obtained from subsequent alkaline hydrolysis. The loss of FA was smaller compared to the pretreatment of WB with hot water. The amount of FA in the hydrolysate was 0.73%. As a result of WB pretreatment with 0.05M NaOH, a significant amount of proteins were removed.

By combining both pretreatment processes (firstly washing with hot water followed by 0.05M NaOH extraction) and subsequent alkaline hydrolysis of pretreated WB, a yield of 0.94 mg/g FA was obtained. During the pretreatment process, the loss of FA was registered, similar to the single pretreatments. The amount of FA in the obtained hydrolysate was 0.71%.

The results of this work show that the pretreatment of native bran is a desirable step in the isolation of FA from WB. In addition to removing part of the unwanted substances after pretreatment, this step also facilitates alkaline hydrolysis since the pretreatment of the material reduces the viscosity of the solution obtained after hydrolysis and allows better processing of the suspension. However, it was found that part of FA is lost during the pretreatment steps. As part of further study, it is therefore necessary to pay attention to the treatment of liquid fractions obtained during WB pretreatment with the aim of recovering the maximum possible amount of FA before the final process of FA separation from the hydrolyzate, such as utilizing ion exchange techniques.

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References:

Apprich, S., Tirpanalan, O., Hell, J., Reisinger, M., Böhmdorfer, S., Siebenhandl-Ehn, S., Novalin, S., Kneifel, W., 2014. Wheat bran-based biorefinery 2: Valorization of products, LWT - Food Science and Technology, 56 (2), 222-231, https://doi.org/10.1016/j.lwt.2013.12.003

Stavova, E., Porizka, J., Stursa, V., Enev, V., Divis, P., 2017. Extraction of ferulic acid from wheat bran through alkaline hydrolysis, PROCEEDINGS OF 24TH INTERNATIONAL PHD STUDENTS CONFERENCE (MENDELNET 2017), 574–579.

Production of biogenic aromatics from lignocellulosic agricultural residues

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Keywords: Lignin depolymerization, Reductive catalytic fractionation, Anaerobic digestion, Digestate valorization, Biogenic aromatics

ABSTRACT

Background. Currently, aromatic base chemicals are almost exclusively produced from fossil petroleum. At the same time, substantial amounts of aromatics are present in biomass, especially in the form of the plant polymer lignin, which is composed of aromatic phenylpropanoids. Many agricultural residues, such as cereal straws, tree pruning wastes and typically digestates from biogas plants contain high amounts of lignocellulose and these biomasses offer the advantage that they do not compete with food production, but often are a by-product of it. Thus, there is a huge potential for the recovery of biogenic aromatics from such lignin-containing agricultural residue biomasses. However, its structural heterogeneity and its resistant crosslinking within the lignocellulose matrix renders the selective depolymerization of lignin to aromatic monomers challenging (Ebikade et al. 2020). In this context, it is a particular challenge that harsh conditions usually applied during conventional lignocellulose fractionation processes, where typically cellulose is the first targeted product, lead to a structural degradation of the lignin. This degradation, also termed as lignin condensation, is caused by diverse repolymerization reactions following the cleavage of ether bonds at harsh conditions and it hampers lignin depolymerization (Lan and Luterbacher 2019).

To avoid lignin condensation, so called “lignin-first” processes are developed, that put the first focus on avoiding lignin condensation. One example is the reductive catalytic fractionation, where the reductive stabilization of lignin fragments with hydrogen is applied in order to avoid repolymerization reactions (Renders et al. 2018). With such processes, high lignin monomer yields close to the theoretical maximum can be achieved from woody biomasses (Galkin and Samec 2016). However, many agricultural biomasses are herbaceous biomasses for which typically much lower monomer yields are achieved than for wood, which is explained by structural differences (stronger acylation, additional phenolic acids as monomers) and higher ash contents (Ebikade et al. 2020).

Research goal. In this work, straw digestates (solid fibres from a straw mono-fermentation biogas plant), as an example for an herbaceous, agricultural, already biologically pre-treated biomass, are investigated as substrates for reductive catalytic fractionation and compared to the utilization of native straw and beech wood. It is hypothesized that higher amounts of lignin monomers can be recovered from straw digestate than from unfermented straw as lignin is not anaerobically degraded and thus accumulating in straw digestates during anaerobic digestion (Steinbrecher et al 2022). Thus, straw digestates could represent a more attractive substrate than straw and wood from an economic perspective due to the higher lignin content and the preceding value creation by biogas production.

Procedure. Solid straw digestate fibres were obtained from an industrial mono-fermentation plant in Brandenburg (Germany) and washed with tap water in order to remove contaminants from the liquid phase. The reductive catalytic fractionation experiments were performed in small-scale screening experiments in 10 mL methanol at 200 °C for 24 h. The type of substrate (beech wood, rye straw, straw digestates), the type of hydrogenation catalyst (Pd, Pt, Ni, Ru on carbon, alumina or silica-alumina) and the H_2 gas pressure during reaction (5 to 60 bar) were varied.

Results and Discussion. The investigated straw digestates had a similar or even higher lignin content (25-28 wt-% based on dry mass) compared to the beech wood (25 wt-%) and the rye straw (15 wt-%). From all these biomasses, lignin monomers (mainly four to six different phenylpropanoids, Figure 1) could be obtained by reductive catalytic fractionation. At 50 bar H_2 pressure, the highest monomer yields on dry

biomass basis are obtained from beech wood with around 100 mg/g (with Pd/C catalyst) compared to 60 mg/g from straw digestate (with Ni/C catalyst) and 40 mg/g from rye straw (with Pd/C catalyst). To take the different lignin contents into account, the yields on lignin basis where calculated, which were again highest from beech wood (41 mole-%C), but in a similar range from straw (26 mole-%C) and straw digestates (25 mole-%C). The monomers 5 and 6 (methyl esters of ferulic acid and coumaric acid, Figure 1) were not detected from beech wood, but together accounted for a share of up to about 35 mole-% of the monomers from straw and straw digestates. This is due to the structural differences of lignin: typically, significant amounts of ferulic acid and coumaric acid are present in the lignin of herbaceous biomass such as straw, whereas they are hardly present in the lignin of many types of wood such as beech wood. Ferulic acid is suspected to lead to a reduction in yield via condensation reactions, which could explain the lower lignin-based yield from straw and straw digestates (Ebikade et al. 2020). There were also some parallels observed in the treatment of herbaceous biomass and wood. For example, the selectivity of monomers from straw digestates can be controlled in a similar way as it was observed for different types of wood in other studies: The use of Pd/C instead of Ru/C as well as an increasing H_2 pressure led to an increased OH-content (i.e., a shift from monomers 1+3 towards 2+4) (Renders et al. 2018, Van den Bosch 2015).

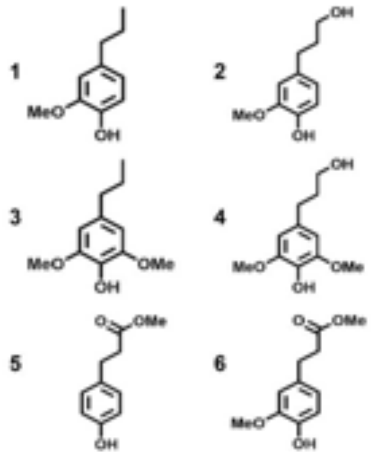

Figure 31: Representation of the most abundantly released monomers after reductive catalytic fractionation of beech wood (monomers 1-4) and straw or straw digestates (monomers 1-6).

Conclusion. It was shown that aromatic monomers can be recovered from straw digestates by reductive catalytic fractionation. Furthermore, the hypothesis that higher amounts of lignin monomers can be recovered from straw digestate than from unfermented straw due to a higher lignin content could be confirmed. Referring to lignin content (i.e., on lignin basis), similar yields are observed from straw and straw digestates. However, the monomer yields from beech wood, both on biomass and lignin basis, are still significantly higher than from straw digestates.

Acknowledgements

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References:

Ebikade, Elvis Osamudiamhen; Samulewicz, Nicholas; Xuan, Shuangqing; Sheehan, James D.; Wu, Changqing; Vlachos, Dionisios G. (2020): Reductive catalytic fractionation of agricultural residue and energy crop lignin and application of lignin oil in antimicrobials. In Green Chem. 22 (21), pp. 7435–7447. DOI: 10.1039/D0GC02781B.

Galkin, Maxim V.; Samec, Joseph S. M. (2016): Lignin Valorization through Catalytic Lignocellulose Fractionation. A Fundamental Platform for the Future Biorefinery. In ChemSusChem 9 (13), pp. 1544–1558. DOI: 10.1002/cssc.201600237.

Lan, Wu; Luterbacher, Jeremy S. (2019): Preventing Lignin Condensation to Facilitate Aromatic Monomer Production. In Chimia 73 (7), pp. 591–598. DOI: 10.2533/chimia.2019.591.

Renders, T.; Cooreman, E.; van den Bosch, S.; Schutyser, W.; Koelewijn, S.-F.; Vangeel, T. et al. (2018): Catalytic lignocellulose biorefining in n -butanol/water. A one-pot approach toward phenolics, polyols, and cellulose. In: Green Chem. 20 (20), S. 4607–4619. DOI: 10.1039/c8gc01031e.

Steinbrecher, Timo; Bonk, Fabian; Scherzinger, Marvin; Lüdtke, Oliver; Kaltschmitt, Martin (2022): Fractionation of Lignocellulosic Fibrous Straw Digestate by Combined Hydrothermal and Enzymatic Treatment. In Energies 15 (17), p. 6111. DOI: 10.3390/en15176111.

Van den Bosch, S.; Schutyser, W.; Koelewijn, S-F; Renders, T.; Courtin, C. M.; Sels, B. F. (2015): Tuning the lignin oil OH-content with Ru and Pd catalysts during lignin hydrogenolysis on birch wood. In Chemical communications (Cambridge, England) 51 (67), pp. 13158–13161. DOI: 10.1039/c5cc04025f.

Promoting environmental justice in urban transitions: An embedded view

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ABSTRACT

Cities around the world are increasingly undergoing sustainability transitions. However, who benefits from the sustainability transitions in practice is often ambiguous. There is increasing evidence that the already well-off benefit the most, leading to further inequalities (Gould & Lewis, 2016). More and more attention is paid to inclusion and participation in urban sustainability transitions, but does it help? Previous notions of justice recognize its multi-dimensionality but fail to guide planning and decision-making processes (Wijsman & Berbés-Blázquez, 2022). In this research, we aim to discover how practitioners understand and apply different dimensions of justice.

An integrative notion of justice is required to guide the planning process and ensure the well-being of all people (Franz et al., 2022). This study is conducted in the context of the Netherlands and involves two steps. In the first step, through an extensive literature review combined with insights from open interviews with professionals, four pillars of environmental justice were identified: 1) having a sense of belonging towards the community and the living environment, 2) fair access to resources (equity), 3) fair representation in the decision-making process (inclusion), and 4) being recognized and valued by society-at-large (diversity). In the second step, we conducted a transdisciplinary workshop in the city of Wageningen. In the workshop, reciprocal relationships among the four dimensions of justice were identified. The findings from this workshop led to the development of the Embedded Environmental Justice Framework (Figure 1). The framework integrates the pillars of diversity, inclusion, equity, and a sense of belonging. This framework considers diversity a necessary condition to achieve other forms of justice. The model emphasizes the dependence of equity on the existence of a fair, inclusive decision-making process. A sense of belonging is at the center of the framework as the ultimate goal of justice. Nonetheless, this goal is firmly embedded in equity, inclusion, and diversity.

The four layers in the framework are interconnected, with the pillars on the outer layers enabling those on the inner layers. From the *outside in*, the recognition of diversity among groups is a critical element that must be in place to enable an inclusive decision-making process, including different perspectives and values. A fair, inclusive decision-making process enables people to actively participate, express their identity, and enhance equity. Equity, achieved through a fair, inclusive decision-making process, allows people to identify themselves and experience a sense of belonging to their community and living environment. The framework also includes feedback from the inner layers to the outer layers, with the inner layers strengthening the outer layers throughout the urban transition process. From the *inside out*, a higher sense of belonging can lead to increased commitment to the urban environment and motivate people to pursue equity improvements. Higher equity provides more opportunities for people to actively participate in decision-making processes. Their diversity can be better recognized through the engagement and collaboration of different groups in the decision-making processes.

This framework strives to guide the operationalization of justice through the interrelated mechanisms of diversity, inclusion, equity, and a sense of belonging. Therefore, it sets the stage for practical actions toward systemic transformations.

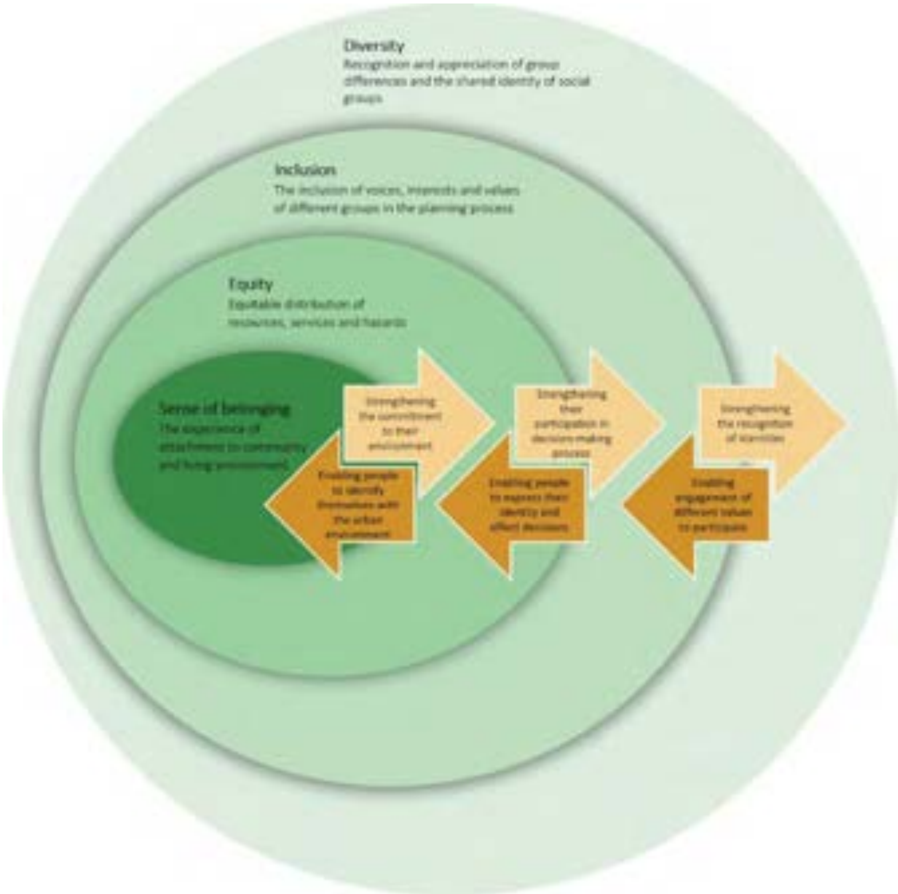

Figure 1- Embedded Environmental Justice Framework

References

Franz, A., Stuiver, M., Harris, E., & Sarabi, S. (2022). Chapter 12: Urban architecture for well-being: a design canvas for inclusive green cities. In M. Stuiver (Ed.), The symbiotic city (pp. 249–270). Wageningen Academic Publishers. https://doi.org/10.3920/978-90-8686-935-0_12

Gould, K. A., & Lewis, T. L. (2016). Green gentrification: Urban sustainability and the struggle for environmental justice. Green Gentrification: Urban Sustainability and the Struggle for Environmental Justice, 1–181. https://doi.org/10.4324/9781315687322

Wijsman, K., & Berbés-Blázquez, M. (2022). What do we mean by justice in sustainability pathways? Commitments, dilemmas, and translations from theory to practice in nature-based solutions. Environmental Science & Policy, 136, 377–386. https://doi.org/10.1016/j.envsci.2022.06.018

Mangrove carbon budgets suggest the estimation of net production and carbon burial by quantifying litterfall

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Keywords: carbon budget, *Kandelia obovata*, *Avicennia marina*, wind speed, precipitation

ABSTRACT

Carbon burial in the soil is a major process enabling mangroves to function as carbon sinks. Only autochthonous carbon sources currently meet the additionality constraint in most carbon accounting protocols. However, the amount of mangrove carbon burial derived from its own production is uncertain. In addition, mangrove production is often laboriously estimated by monitoring the stem height and diameter of mangrove stems. In this study, ten carbon budgets covering a variety of habitat features were constructed for the two dominant mangrove species (*Kandelia obovata* and *Avicennia marina*) with distinct root structures in subtropical and tropical Taiwan from 2011 to 2019. The carbon budgets suggest that the litterfall: net production ratio was 20.1% ± 4.7% for *K. obovata* and 48.2% ± 5.3% for *A. marina*. The mangrove-derived carbon burial rate was 0.25 ~ 1.55 Mg C ha^{-1} yr^{-1} for *K. obovata* mangroves and 0.36 ~ 1.00 Mg C ha^{-1} yr^{-1} for *A. marina* mangroves. Combined with other studies using the same species, there were positive and linear correlations between the carbon burial rate and litterfall production rate for the two mangroves. The carbon burial rate for *K. obovata* and *A. marina* can be estimated using 14.8% ± 7.5% and 10.9% ± 4.4% of the litterfall production rate, respectively. The results of dbRDA with DistLM models showed that wind speed and precipitation were the main factors affecting carbon burial in *K. obovata* and *A. marina* mangroves, respectively. The carbon budgets suggest that litterfall production can be efficiently used to estimate the net production and soil carbon burial of *K. obovata* and *A. marina*.

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Biochar supported Ag-TiO_2: A green catalyst for degradation of pharmaceutically active compounds and disinfection in wastewater

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Keywords: Sludge derived biochar, Biochar/Ag-TiO_2 nanoparticles, Pharmaceutically active compounds, Photocatalysis, Disinfection

ABSTRACT

Visible light driven photocatalysis process has received wide acceptability in removing organic compounds from wastewater due to its rapidness, economic and eco-friendly characteristics. Traditional semiconductor catalysts (e.g. TiO_2) can be modified by metal doping to decrease the bandgap energy [1]. On other hand, utilization of biowaste-derived biochar can act as an immobilization matrix to enhance catalyst reusability with increased porosity, surface area, charge carrier mobility and also by ensuring waste management [2]. In current study, a green biochar/Ag-TiO_2 (BAT) catalyst was synthesized by adding sludge-derived biochar as a support matrix to Ag doped TiO_2 (Ag:Ti in 1:1.7 molar ratio) nanoparticles for removing pharmaceutically active compounds (PhACs) with disinfection from wastewater. The sludge was collected from a food waste anaerobic digester and was dried and pyrolyzed at 450° C temperature for 2 h to obtain the biochar. The acid activated biochar (>20 µm) was mixed with Ag-TiO_2 sol-gel (Biochar:Ti in 1:2 w/w ratio), which was further dried, calcined (450° C, 2 h) and ground into fine particles [3, 4]. The surface morphology, functional groups, crystallinity, and optical properties of the BAT catalyst are characterized by SEM-EDX, FTIR, XRD, UV-DRS and photo luminescence analysis [5]. The photocatalytic property of BAT was examined for degradation of a model PhAC tetracycline (TCE) and inactivation of *Escherichia coli* in wastewater. A baseline study was conducted at neutral pH by adding 0.5 g/L of BAT in 5 mg/L initial TCE solution suspended with 10^6 CFU/mL of *E. coli* cells at continuous mixing in presence of blue LED lights for 225 min considering the initial 45 min as the dark adsorption period [6, 7]. BAT could achieve about 62-66% TCE removal along with 4-6 log of *E. coli* disinfection. Ag doping and biochar immobilization promoted separation of photogenerated electron-hole pairs, easy separation and reusability of the catalyst. In addition, studies on optimization of operational parameters, reusability of the catalyst, and role of reactive species are carried out to understand the plausible mechanism of photocatalytic PhAC removal and disinfection by BAT.

References

[1] Liu, G., Wang, L., Yang, H. G., Cheng, H.-M., & (Max) Lu, G. Q. (2010). Titania-based photocatalysts—crystal growth, doping and heterostructuring. *J. Mater. Chem*., 20(5), 831–843. https://doi.org/10.1039/B909930A

[2] Shi, M., Wei, W., Jiang, Z., Han, H., Gao, J., & Xie, J. (2016). Biomass-derived multifunctional TiO 2/carbonaceous aerogel composite as a highly efficient photocatalyst. *RSC Adv.*, *6*(30), 25255-25266. 10.1039/C5RA28116D

[3] Karim, A.V. and Shriwastav, A. (2020). Degradation of ciprofloxacin using photo, sono, and sonophotocatalytic oxidation with visible light and low-frequency ultrasound: degradation kinetics and pathways. *Chem. Eng. J.* 392, 124853. https://doi.org/10.1016/j.cej.2020.124853

[4] Zhang, S., & Lu, X. (2018). Treatment of wastewater containing Reactive Brilliant Blue KN-R using TiO2/BC composite as heterogeneous photocatalyst and adsorbent. *Chemosphere*. 206, 777-783. https://doi.org/10.1016/j.chemosphere.2018.05.073

[5] Fazal, T., Razzaq, A., Javed, F., Hafeez, A., Rashid, N., Amjad, U. S., & Rehman, F. (2020). Integrating adsorption and photocatalysis: A cost effective strategy for textile wastewater treatment using hybrid biochar-TiO_2 composite. *J. Hazard. Mater. 390*, 121623. https://doi.org/10.1016/j.jhazmat.2019.121623

[6] Hou, C., Jiang, X., Chen, D., Zhang, X., Liu, X., Mu, Y., & Shen, J. (2022). Ag-TiO_2/biofilm/nitrate interface enhanced visible light-assisted biodegradation of tetracycline: The key role of nitrate as the electron accepter. *Water Res.* 215, 118212. https://doi.org/10.1016/j.watres.2022.118212

[7] Sreeja, S. and Shetty, V. (2017). Photocatalytic water disinfection under solar irradiation by Ag@TiO_2 core-shell structured nanoparticles. *Sol. Energy.* 157, 236-243. https://doi.org/10.1016/j.solener.2017.07.057

Microbial fuel cells as a sustainable pathway to remediate oil-contaminated sediments and soils

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Keywords: bioremediation, microbial fuel cell, oil pollution, sediment

ABSTRACT

Addressing the complex challenges posed by managing and mitigating oil-contaminated soil and sediments highlights the essential need for innovative, environmentally friendly, and sustainable remediation methods. Amid these challenges, microbial fuel cells emerge as promising solutions to enhance microbial oxidation of organic pollutants in soil or sediments. These systems can serve as sustainable, low-cost, and low-maintenance solutions for soil and sediment bioremediation.

The current study sought to explore the efficacy of MFC for treating various types of oil-contaminated sediments. Our investigation encompassed the oil biodegradation efficiency and changes in microbial community abundance, phylogenetic, and functional structure in MFC units. These parameters were monitored using advanced microbiological techniques such as quantitative PCR, amplicon-based, and shotgun metagenomics.

The MFC units deployed in this study consisted of a single chamber, containing 300g of sediment, equipped with graphite-based electrodes (anode at the bottom and cathode on the sediment surface). Sediment samples were obtained from the Baltic Sea's anoxic zone and were spiked with various pollutants including crude oil (5% w/w), marine fuel IFO 180 (5% w/w), and crude oil in conjunction with dispersant Finasol 52.

The results of the 30-day experiment pointed toward promising outcomes. The highest oil removal rate (45%) was achieved for MFC units treating crude oil mixed with the dispersant, showcasing the potential of this method in biodegrading such complex mixtures. Comparatively, the removal rates of IFO 180 and crude oil were lower at 32% and 28%, respectively.

Observation of voltage dynamics offered additional insights. MFC units treating crude oil and IFO 180 showed a slow increase in power output during the first ten days, stabilizing after that. However, the MFC unit with crude oil and dispersant demonstrated initially low power output with a rapid voltage increase on the 5th day. The maximum power output (30.6 μW) was recorded for this unit, further reinforcing its efficacy.

Microbial community dynamics varied with the type of contaminant. There was a slight increase in bacterial abundance in IFO180 MFC units while adding dispersant to crude oil resulted in a halving of this value. Similarly, dispersant addition led to a decrease in archaeal abundance. The study results emphasize the need for an integrated understanding of the influence of various contaminants and additives on electroactive microbial communities for efficient biodegradation of pollutants in MFC. Given the potential environmental concerns linked to applying synthetic dispersants for oil pollution mitigation, future studies exploring the use of naturally derived biosurfactants could pave the way for even more sustainable MFC-based remediation strategies.

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Cyanobacterial biocrust development on biomineralized sandy soil: new dryland restoration method

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Keywords: Biological soil crust, Calcium carbonate, Land rehabilitation, Microbiologically induced calcite precipitation, Soil stabilization, Wind erosion potential

ABSTRACT

Land degradation and desertification are growing global problems, exacerbated by climate change; effective land restoration techniques are urgently needed. Various land restoration techniques have been studied and implemented to prevent desertification and restore degraded land. Land restoration techniques that utilize biocrusts have recently attracted much attention (Chamizo et al., 2018; Rossi et al., 2017; Zhao et al., 2016). Biocrusts are thin, film-like structures on the soil surface made up of tiny organisms and soil particles (Belnap et al., 2016). These organisms have a high survival rate in harsh environments (Rodríguez-Caballero et al., 2019) and perform various ecological functions, such as carbon and nitrogen fixation, instead of vegetation (Rodríguez-Caballero et al., 2018). However, biocrusts are extremely sensitive to physical disturbances (Warren, 2003; Zaady et al., 2016). In degraded areas, soil surface stabilization is often required before biocrust inoculation, but optimal stabilizing methods require further investigation. This study focused on biomineralization as a soil stabilizing method. Biomineralization is a biochemical process induced by organisms such as coral, shells, and microorganisms (Estroff, 2008). Ureolytic bacteria perform biomineralization and precipitate calcium carbonate on their outer surface, bonding sand particles (Nayanthara et al., 2019). Biomineralization can strengthen the soil surface against water and wind erosion (Li et al., 2020) and soil moisture retentivity (Liu et al., 2021). The biocrust development on the stable biomineralized soil, however, has not been tested.

We examined whether biomineralization by ureolytic bacteria could facilitate biocrust-forming cyanobacteria growth and the cyanobacterial biocrust development. We investigated whether biomineralization and cyanobacterial inoculation could improve soil stabilization, hydrology, and photosynthesis activity. We also checked whether this facilitating effect was active under physical disturbance and small-volume and high-frequency rainfall.

We filled Petri dishes with biomineralized soil or bare soil and inoculated them with biocrust-forming cyanobacteria. We incubated the biocrusts under no stress, disturbing stress, and water input stress. The physical disturbing stress was reproduced by falling weight on the Petri dishes. The frequency of watering was arranged to reproduce high-frequency rainfall. After the incubation, several indicators were measured to evaluate the cyanobacterial growth, biocrust structure development, and ecological functions.

This paper introduces the results of the incubation with no stress and the preliminary results of the incubation under the above two environmental stresses.

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References:

Belnap, J., Weber, B., Büdel, B. 2016. Biological soil crusts as an organizing principle in drylands. In: Belnap, J., Weber, B., Büdel, B.(eds), Biological Soil Crusts: An Organizing Principle in Drylands, Springer, Switzerland, pp. 3-8.

Chamizo, S., Mugnai, G., Rossi, F., Certini, G., De Philippis, R. 2018. Cyanobacteria inoculation improves soil stability and fertility on different textured soils: gaining insights for applicability in soil restoration. Frontiers of Environmental Science 6(49), 1-14, https://doi.org/10.3389/fenvs.2018.00049.

Estroff, L. A. 2008. Introduction: biomineralization. Chemical reviews, 108(11), 4329-4331, https://doi.org/10.1021/cr8004789.

Li, S., Li, C., Yao, D., Wang, S. 2020. Feasibility of microbially induced carbonate precipitation and straw checkerboard barriers on desertification control and ecological restoration. Ecological Engineering, 152, 105883, https://doi.org/10.1016/j.ecoleng.2020.105883.

Liu, B., Tang, C.-S., Pan, X.-H., Zhu, C., Cheng, Y.-J., Xu, J.-J., Shi, B. 2021. Potential drought mitigation through microbial induced calcite precipitation-MICP. Water Resources Research, 57, e2020WR029434, https://doi.org/10.1029/2020WR029434.

Nayanthara, P.G.N., Dassanayake, A.B.N, Nakashima, K., Kawasaki, S. 2019. Microbial induced carbonate precipitation using a native inland bacterium for beach sand stabilization in nearshore areas. Applied Sciences, 9(15), 3201, https://doi.org/10.3390/app9153201.

Rodríguez-Caballero, E., Belnap. J., Büdel, B., Crutzen, P. J., Andreae, M. O., Pöschl, U., Weber, B. 2018. Dryland photoautotrophic soil surface communities endangered by global change. Nature Geoscience, 11, 185-189, https://doi.org/10.1038/s41561-018-0072-1.

Rodríguez-Caballero, E., Román, J. R., Chamizo, S., Ramos, B. R., Cantón, Y. 2019. Biocrust landscape-scale spatial distribution is strongly controlled by terrain attributes: Topographic thresholds for colonization in a semiarid badland system. Earth Surface Process and Landforms, 44(14), 2771-2779, https://doi.org/10.1002/esp.4706.

Rossi, F., Li, H., Liu, Y., Philippis, R.D. 2017. Cyanobacterial inoculation (cyanobacterisation): Perspectives for the development of a standardized multifunctional technology for soil fertilization and desertification reversal, Earth-Science Reviews, 171, 28-43, https://doi.org/10.1016/j.earscirev.2017.05.006.

Warren, S.D. 2003. Biological soil crusts and hydrology in North American deserts. In: Belnap, J., Lange, O. (eds), Biological soil crusts: Structure, function, and management, Springer, Berlin, pp. 327-337.

Zaady, E., Eldridge, D.J., Bowker, M.A. 2016. Effects of local-scale disturbance on biocrusts. In: Belnap, J., Weber, B., Büdel, B.(eds), Biological Soil Crusts: An Organizing Principle in Drylands, Springer, Switzerland, pp.429-450.

Zhao, Y., Bowker, M.A., Zhang, Y., Zaady, E. 2016. Enhanced recovery of biological soil crusts after disturbance. In: Belnap, J., Weber, B., Büdel, B.(eds), Biological Soil Crusts: An Organizing Principle in Drylands, Springer, Switzerland, 499-523.

Green pepper (Capsicum annuum) fruit quality. Effects of the application of biostimulants obtained from slaughterhouse sludge

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Keywords: Biostimulant; Slaughterhouse sludge; Green pepper; Fruit quality

ABSTRACT

Currently, one of the most important challenges for agriculture is to produce enough food to meet the needs of the world population in a sustainable way (Ávila-Pozo et al., 2022).

The use of biostimulants (BS) obtained by the enzymatic hydrolysis process has been proposed as a promising, safe and effective alternative to address the sustainability challenges facing agriculture and to guarantee high yield and quality of agricultural products (Tejada et al., 2018; 2022).

Animal waste obtained from slaughterhouses is characterized by having a high protein content (Izydorcyk et al., 2022). Avila-Pozo et al. (2022) obtained a BS from slaughterhouse sludge by enzymatic hydrolysis and applied it to a tomato crop by foliar and root route. The results obtained indicated that this BS significantly improved the morphological parameters of the plant as well as the production and nutritional quality of said crop.

Green pepper (Capsicum annuum) is a crop of great agronomic importance in the Mediterranean area due to the nutritional value of its fruits, since it contains many antioxidant, phenolic, vitamin C and carotenoid compounds (Rosa-Martínez et al., 2021).

The main objective of this study is to study the effect of applying a BS obtained by enzymatic hydrolysis from slaughterhouse sludge and applied by foliar and root application on the macro and micronutrients and vitamin C content of green pepper (Capsicum annumm) fruits.

The BS was obtained from slaughterhouse sludge supplied by the company "Mataderos del Sur" (Salteras, Seville, Andalusia, Spain). The process of obtaining said BS is detailed in the study carried out by Ávila-Pozo et al. (2022).

The experiment was carried out in a greenhouse under controlled humidity and temperature conditions (humidity: 80%; temperature: 25 ºC).

Sweet green pepper plants 15-17 cm tall purchased from a commercial nursery were planted in 25-L pots with a universal substrate (Blumenerde, Gramoflor) as culture medium.

Before applying the BS, the plants were allowed to grow for 30 days so that they had a good adaptation to the pot.

After these 30 days, two doses of the experimental BS were used (0.7 and 1.4 g/L, respectively).

The Bs was applied to the substrate or foliarly to the plant every 20 days. Said application was at 20, 40, 60 and 80 days after the indicated adaptation time, in such a way that the total doses of BS used were 2.8 and 5.6 g/L.

Throughout the experimental period, different fruits were collected for each fertilizer treatment. The selected fruits were freeze-dried and crushed before analysis. N, P, K, S, Ca, Mg, Fe, Cu, Mn and Zn were determined. The methodology used to determine these nutrients is described in Ávila-Pozo et al. (2022).

On the other hand, the vitamin C content in the fruit was extracted according to the methodology described by Paradikovic et al., 2011. For this, 5 g of fruit were homogenized in 100 mL of distilled water for 30 minutes. The homogenate was filtered and centrifuged, using the supernatant to determine said vitamin C by means of the method described by Benderitter et al. (1998).

The results obtained indicated a higher content of macro and micronutrients as well as vitamin C in the peppers fertilized with BS via the roots and at a higher dose. These results coincide with those obtained by Ávila-Pozo et al. (2022) who obtained higher tomato fruit and their quality when they applied the BS at a higher dose and root route. According to these authors, when applying the BS through the roots, the plant had a greater root development that allowed a greater absorption of nutrients and, consequently, a greater production and quality of the harvest.

References:

Ávila-Pozo, P., Parrado, J., Caballero, P., Tejada, M. (2022). Use of a biostimulant obtained from slaughterhouse sludge in a greenhouse tomato crop. *Horticulturaee*, 8, 622. https://doi.org/10.3390/horticulturae8070622.

Benderitter, M., Maupoil, V., Vergely, C., Dalloz, F., Briot, F., Rochette, L. (1998). Studies by electron paramagnetic resonance of the importance of iron in the hydroxyl scavenging properties of ascorbic acid in plasma: effects of iron chelators. *Fundamental nad Clinical Pharmacology*, 12, 510-516. https://doi.org/10.1111/j.1472-8206.1998.tb00979.x.

Izydorcyk, G., Mikula, K., Skrzypczak, D., Witek-Krowiak, A., Mironiuk, M., Furman, K., Gramza, M., Monstakask, K., Chojnacka, K. (2022). Valorization of poultry slaughterhouse waste for fertilizr purposes as an alternative for thermal utilization methods. *Journal of Hazardous Materials*, 424, 127328. https://doi.org/10.1016/j.jhazmat.2021.127328.

Paraikovic, N., Vinkovic, T., Vrcek, I.V., Zunter, I., Bojic, M., Medic-Saric, M. (2011). Effect of natural biostimulants on yiled and nutritional quality: an example of sweet yellow pepper (capsicum annuum, L.) plants. *Journal of the Science Food and Agriculture*, 91, 2146-2152. https://doi.org/10.1002/jsfa.4431

Rosa-Martínez, E., García-Martínez, M.D., Adalid-martínez, A.M., Pereira-Dias, L., Casanova, C., Soler, E., Figas, M.R., Raigón, M.D., Plazas, M., Soler, S., Prohens, J. (2021). Fruit compsition profile of pepper, tomato and eggplant varieties grow under uniform conditions. *Food Research International*, 147, 110531. https://doi.org/10.1016/j.foodres.2021.110531

Tejada, M., Caballero, Parrado, J. (2022). Effects of foliar fertilization of biostimulants obtained from sewage sludge on olive yield. *Cogent Food & Agriculture*, 8, 2124702. https://doi.org/10.1080/23311932.2022.2124702.

Tejada, M., Rodríguez-Morgado, B., Paneque, P., Parrado, J. (2018). Effects of foliar fertilization of a biostimulant obtained from chiken feathers on maize yield. *European Journal of Agronomy*, 96, 54-59. https://doi.org/10.1016/j.eja.2018.03.003.

Application of a biostimulant obtained by enzymatic hydrolysis from slaughterhouse sludge in the bioremediation of soils polluted by the imazamox herbicide

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Keywords: Soil bioremediation; Imazamox; Biostimulant; Slaughterhouse sludge; Soil biochemical properties

ABSTRACT

Pesticides are compounds that are used in agriculture with the aim of eliminating possible pests caused by weeds, insects or pathogens that can cause a negative effect on crop development (Nehra et al., 2021).

However, the continued use of these pesticides can cause serious environmental problems in soils and aquifers that depend on the degree of persistence of the pesticide in the soil. Thus, the lower the degradation of the pesticide and, consequently, the greater its persistence, the greater the risk of environmental contamination (Barba et al., 2017; Manjarres-López et al., 2021).

Imazamox, (RS)-2- (4-isopropyl-4-methyl-5-oxo-2-imidazolin-2-yl)-5-methoxymethylnico-tinic acid, ($C_{15}H_{19}N_3O_4$), is a broad-spectrum product herbicide used on soy, wheat, rice, maize, etc., (Shane, r2014). Imazamox in soil not only affect crops, but also affects to biochemical activity of non-target organisms (Hu et al,. 2020; Ortiz-Botella et al., 2022).

Vasic et al. (2019) found a reduction in the total content of bacteria and aminoheterotrophic microorganisms in the soil 60 days after applying the herbicide at a dose of 0.048 kg/ha. Also, Ortiz-Botella et al. (2022) found a decrease in the biochemical activity of the soil when they applied imazamox at the dose recommended by the manufacturer (2.5 l/ha).

The application of various biostimulants (BS) rich in amino acids and low molecular weight peptides is a very common environmental practice in order to reduce or eliminate the toxic effects caused by pesticides in soils (Ortiz-Botella et al., 2022; Tejada et al., 2022). These BSs are characterized by presenting a high number of low molecular weight peptides, amino acids, etc. that are easily absorbed by soil microorganisms, thus accelerating the degradation of the pollutant in the polluted.

The objective of this study was to study under laboratory conditions the behaviour of a BS obtained from slaughterhouse using subtilisin enzyme in the biorremediation of a soil polluted with imazamox and its influence on the soil biological properties.

To carry out this bioremediation experiment, an agricultural sandy clay loam soil from southern Spain classified as Arenic Calcaric Regosol, whose physical-chemical properties are described in Tejada et al. (2022). Also, the chemical characteristics of the biostimulant as well as its production are detailed as shown in Tejada et al. (2022).

For this experiment, 300 g of soil was used, mixed with the biostimulant at a dose of 1 %. The treatments that were carried out were the following: (1) C, control soil, non-polluted soil and non-organically

amended; (2) B, non-polluted soil and amended with BS; (3) I, imazamox-polluted soil and non-organically amended; and (4) IB, imazamox-polluted soil and amended with BS.

Imazamox and various enzyme activities (dehydrogenase, urease, β-glucosidase and alkaline phosphatase) were determined in triplicate at 2, 6, 9, 14, 21, 35, 50 and 72 during the incubation experiment.

The results obtained indicated that imazamox causes a toxic effect on the biochemistry of the soil. At the end of the incubation period and after the application of the BS to the contaminated soil, the inhibition of the studied enzymatic activities decreased. The imazamox concentration in soil decreased by 28%. According to Tejada et al. (2022) this is due to the stimulation of imazamox-tolerant microorganisms in the soil.

These results suggest that the use of this BS obtained from slaughterhouse sludge would be very useful in the bioremediation of soils contaminated by the imazamox herbicide.

References:

Barba, S., Villaseñor, J., Rodrigo, M.A., Cañizares, P. 2017. Effect of the polarity reversal frequency in the electrokinetic-biological remediation of oxyfluorfen polluted soil. *Chemosphere*, 177, 120-127. https://doi.org/10.1016/j.chemosphere.2017.03.002.22.

Hu, M., Liu, K., Qiu, J., Zhang, H., Li, X., Zeng, D., Tan, H. 2020. Behavior of imidazolinone herbicide enantiomers in earthworm-soil microcosms: Degradation and bioaccumulation. Science of the Total Environment 707, 135476. doi: 10.1016/j.scitotenv.2019.13476..

Manjarres-López, D.P., Soledad Andrades, M., Sánchez-González, S., Rodríguez-Cruz, S., Sánchez-Martín, M.J., Herrero-Hernández, E. 2021. Assessment of pesticide residues in waters and soils of a vineyard region and its temporal evolution. *Environmental Pollution*, 284, 117463. https://doi.org/10.1016/j.envpol.2021.117463.

Nehra, M., Dilbaghi, N., Marazza, G., Kaushik, A., Sonne, C., Kim, K.H., Kumar, S. 2021. Emerging nanobiotechnology in agriculture for the management of pesticide residues. *Journal of Hazardous Materials*, 401, 123369. doi: 10.1016/j.jhazmat.2020.123369.

Ortiz-Botella, M., Gómez, I., Paneque, P., Caballero, P., Parrado, J., vera, A., Bastida, F., García, C., Tejada, M. (2022). Use of biostimulants obtained from okara in the bioremediation of soils polluted by imazamox. *Bioremediation Journal*, 26, 53-63. https://doi.org/10.1080/10889868.2021.1884531

Shaner, D.L.(2014). Herbicide handbook. 10th ed. Lawrence,KS: Weed Science Society of America, 513.

Tejada, M., Macias-Benitez, S., Caballero, P., Gómez, I., Paneque, P., Parrado, P. (2022). Bioremediation of an oxyfluorfen-polluted soil using biostimulants obtained by fermentation processes: Effect on biological properties. *Applied Soil Ecology*, 170, 104270. https://doi.org/10.1016/j.apsoil.2021.104270.

Vasic, V., Djuric, S., Jafari-Hajnal, T., Orlovic, T., Vasic, S., Pajnik, P., Galović, V. (2019). The microbiological response of forest soils after application of nicosulfuron, imazamox and cycloxydim. *International Journal of Environmental Science and Technology* 16 (5), 2305-2312. doi:10.1007/s13762-018-1862-0.

Drone monitoring of extractive activities in Catalonia: a collaborative system for improving the sustainable management of the mining sector

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Keywords: Open-pit Mining Areas; UAS; Remote Sensing; Restoration; Land Cover Maps; Erosion Processes.

ABSTRACT

The following summary shows some of the results obtained in drone monitoring of extraction and restoration processes in the context of open-pit mining industry in Catalonia (NE Iberian Peninsula). A collaborative workflow has been established between the environmental administration (Service for Information, Inspection and Environmental Control of Activities, Government of Catalonia) and the research center (CREAF), with the collaboration of the Rural Agents Corps (RPAS Unit). The environmental administration is the responsible of selecting the mines for monitoring, due to the special interest for the impact that they generate. The RPAS Unit is the responsible of carrying out the flight operations. Finally, the research center generates the products required for the inspection according to the administration needs and investigates in the generation of new procedures and tools for improving monitoring.

The UAS used were low-cost equipment, equipped with a RGB camera with a 1" CMOS sensor of 20 Mpx. For the implementation of this study, Geographic Information Systems (GIS) and remote sensing using UAS, including supervised classification algorithms (KNN, k-nearest neighbors) and digital photogrammetry (SfM, (Carrivick et al., 2016, Micheletti, 2015)) are used, thus following the methodology proposed in previous works (Carabassa et al. 2020, Padró et al. 2019).

The main products obtained that stand out are I) topographic maps and terrain models with centimetric resolutions derived from the point cloud obtained from the SfM process; II) orthophotography and III) canopy maps, being able to distinguish the different vegetation strata and bare soil or rock. In addition, it is possible to obtain relief models derived from the elevation model (Flow accumulation models, Fairfield and Leymarie, 1991) that allow detecting the areas of the relief where water circulation is preferential and therefore automatically detect potential erosion processes by surface runoff. Using the data obtained by the drone sensor, it is also possible to calculate vegetation indices to evaluate the state of plant vigour, or to quantify the effect of dust particles generated by mining activity and deposited on the surrounding vegetation cover.

On the other hand, by means of surface interpolation, it is possible to approximate a calculation of volumes of stockpiled materials, future fillings of rocky fronts or depressed reliefs for the geomorphological restoration of the environment. Finally, using the elevation model obtained by the drone and integrating it with official cartography data (LIDAR v2 and orthophotographs), it is possible to analyse, in a nearby environment (5 km approx.), possible potential sites for visualization of mining activity, and therefore evaluate the landscape (visual) impact.

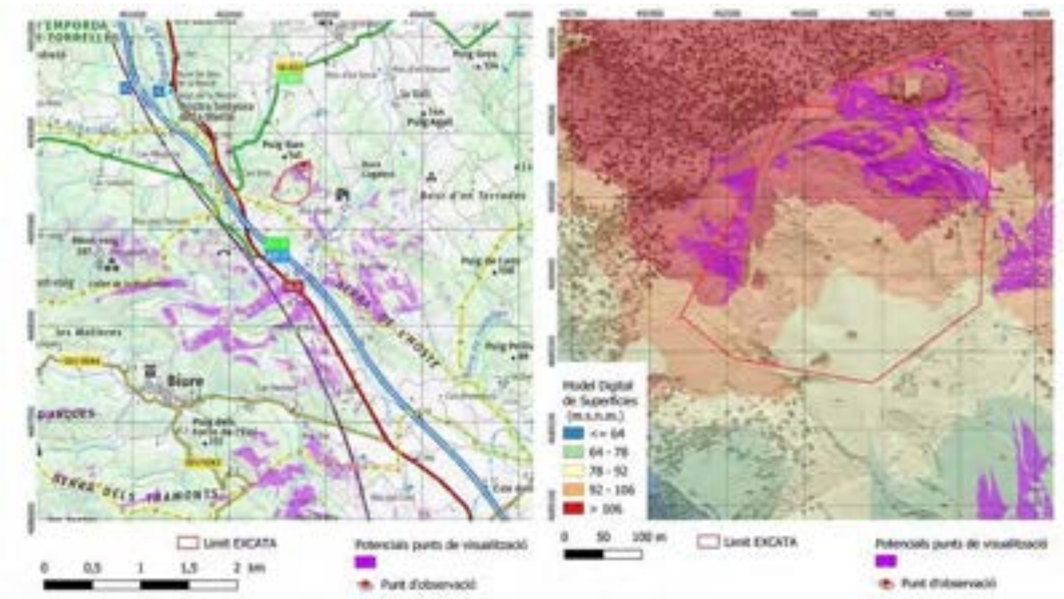

Figure 2. Map of the visual basin from the highest part of a mining activity. Background image data extracted from ICGC (2022).

Thus, through these analysis techniques, it is possible to quantify and monitor efficiently and quickly the processes in mining environments, both those relevant for the stock/mineral extraction, as well as those related to the restoration of the environment disturbed by the extraction activity. In such a way, these techniques can contribute to increase the sustainability of the activity in its environment.

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References

Carabassa, V., Montero, P., Crespo, M., Padró, J.C, Pons, X., Balagué, J., Brotons, LL. & Alcañiz J.M. (2020). Unmanned aerial system protocol for quarry restoration and mineral extraction monitoring. Sci Total Environ, 270. https://doi.org/10.1016/j.jenvman.2020.110717

Carrivick JL, Smith MW, Quincey DJ. (2016). Structure from motion in the geosciences. First Edit. John Wiley & Sons, Ltd;.

Fairfield J, Leymarie P. (1991) Drainage Networks From Grid Digital Elevation Models. WATER Resour RESEARC;27:709–17

Institut Cartogràfic i Geològic de Catalunya, ICGC (2022). Dades LIDAR. https://www.icgc.cat/ca/Descarregues/Elevacions/Dades-lidar.Consultada el 10/04/2023.

Micheletti N. (2015). Structure from motion (SFM) photogrammetry. In: Clarke, L.E. and Nield J., editor. Geomorphol. Tech., British Society for Geomorphology;

Padró, J.-C.; Carabassa, V.; Balagué, J.; Brotons, L.; Alcañiz, J.M.; Pons, X. Monitoring opencast mine restorations using Un-manned Aerial System (UAS) imagery. STOTEN 2019, 657, 1602–1614. https://doi.org/10.1016/j.scitotenv.2018.12.156.

Design of a CHEMICAL/BIOLOGICAL biphasic process for circular economy for the conversion of polyurethane into agronomic biostimulants.

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Keywords: PolyUrethane, PGP, Chemical, Biodegradation.

ABSTRACT

This paper presents a new circular economy process for the valorization of PolyUrethane (PU), which is converted into proteins and bacterial biomass with Plant Growth Promoting (PGP) activity.

Polyurethanes (PU) are a type of plastic polymers used as foams in car seats, coatings, sealants, textile industry, etc., with an estimated production of around 27-30 million tons annually (Danso et al., 2019). The management of polyurethane waste poses challenges due to its non-biodegradable nature and durability. Disposing of polyurethane waste in landfills can occupy significant space and contribute to environmental issues. Therefore, various strategies are employed to manage polyurethane waste, including recycling, transforming it into raw materials for new polyurethane products (Orts et al., 2023). Chemical recycling methods can also be used to break down polyurethane into its original components for recovery and reuse. Landfill disposal is considered the least favorable option from an environmental perspective (Liu et al., 2022).

PU foams are synthesized through the reaction of diisocyanate (R-N=C=O) and polyol (R'-OH) (Fig. 1), generating organic units called urethane (Xie et al., 2019). The numerous urethane groups joined together form a polyurethane molecule (Mahajan & Gupta, 2015) that is highly resistant to both physical and biological degradation due to its chemical composition, which provides high temperature resistance, hydrophobicity, etc., thus increasing its lifespan for decades (Gaytán et al., 2020).

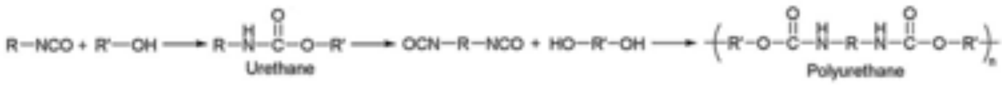

Fig. 1. Polyurethane synthesis mechanism.

The process presented in this communication is biphasic, with a first chemical phase (patent pending) that leads to complete depolymerization of PU in water, converting its long and linear molecule into small-molecular-weight molecules with high content of essential elements for life, such as Carbon and Nitrogen. The second phase is a biological phase, where these molecules are metabolized and converted into new bio-stimulant products for agriculture, such as proteins and PGPbs bacteria (Fig. 2).

The depolymerization phase is carried out in an aqueous solution, achieving the solubilization of the polymer in water, transforming it into OLE (Organic Liquid Extract), a solution composed of small organic molecules with sizes smaller than 600 Daltons, which have been characterized by HPLC-LC-MS. The OLE mainly consists of polyols (derived from Polyethylene Glycol) and chemically modified diisocyanates.

This solution of molecules (OLE) is susceptible to be metabolized by environmental microorganisms. Different environmental bacteria capable of utilizing OLE as the sole source of carbon, nitrogen, and energy have been isolated and identified. These bacteria convert the chemically-based molecules into biologically-originated ones, such as proteins or biomass.

Fig. 2. Scheme of the two-phase process for the recovery of Polyurethane

These OLE-metabolizing bacteria belong to the metabolically versatile family Bacillus, specifically Bacillus licheniformis and Bacillus siamensis, known for their potential as Plant Growth Promoting bacteria (PGPb). Other bacteria such as Paracoccus versutus and Corynebacterium variabile are also capable of metabolizing OLE. These bacteria have been characterized as PGPB, exhibiting various activities such as phosphate solubilization, nitrogen fixation, production of siderophores and auxins, biofilm formation, and enzymatic activities like DNAse, lipase, protease, etc.

Conclusion:

Through our biphasic process, we convert a long and hardly biodegradable molecule like PU into low-molecular-weight molecules that can be metabolized and biotransformed into biologically-originated molecules using cultivation techniques with bacteria that possess PGPb capabilities and can utilize them as the sole source of carbon, nitrogen, and energy.

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References:

Danso, D., Chow, J., & Streita, W. R. (2019). Plastics: Environmental and biotechnological perspectives on microbial degradation. *Applied and Environmental Microbiology*, *85*(19), 1–14. https://doi.org/10.1128/AEM.01095-19

Gaytán, I., Sánchez-Reyes, A., Burelo, M., Vargas-Suárez, M., Liachko, I., Press, M., Sullivan, S., Cruz-Gómez, M. J., & Loza-Tavera, H. (2020). Degradation of Recalcitrant Polyurethane and Xenobiotic Additives by a Selected Landfill Microbial Community and Its Biodegradative Potential Revealed by Proximity Ligation-Based Metagenomic Analysis. *Frontiers in Microbiology*, *10*(January). https://doi.org/10.3389/fmicb.2019.02986

Liu, J., Liu, J., Xu, B., Xu, A., Cao, S., Wei, R., Zhou, J., Jiang, M., & Dong, W. (2022). Biodegradation of polyether-polyurethane foam in yellow mealworms (Tenebrio molitor) and effects on the gut microbiome. *Chemosphere*, *304*(December 2021). https://doi.org/10.1016/j.chemosphere.2022.135263

Mahajan, N., & Gupta, P. (2015). New insights into the microbial degradation of polyurethanes. *RSC Advances*, *5*(52), 41839–41854. https://doi.org/10.1039/c5ra04589d

Orts, J. M., Parrado, J., Pascual, J. A., Orts, A., Cuartero, J., Tejada, M., & Ros, M. (2023). Polyurethane Foam Residue Biodegradation through the Tenebrio molitor Digestive Tract: Microbial Communities and Enzymatic Activity. *Polymers*, *15*(1). https://doi.org/10.3390/polym15010204

Xie, F., Zhang, T., Bryant, P., Kurusingal, V., Colwell, J. M., & Laycock, B. (2019). Degradation and stabilization of polyurethane elastomers. *Progress in Polymer Science*, *90*, 211–268. https://doi.org/10.1016/j.progpolymsci.2018.12.003

Effect of sewage sludge mono- and co-digestion on nutrients removal from reject water

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ABSTRACT

Introduction

High-performance wastewater treatment systems generate significant amounts of sludge. Their annual production in the EU-28 is currently more than 9.5 million tons of s.m., and a total of 1,025,800 tons of s.m. (dry matter) were generated in Poland in 2021. (Campo 2021, Statistic Poland) Sewage sludge is a valuable source of nutrients to be recovered for soil fertilization and remediation (Domini 2022). Phosphorus and nitrogen recovery is extremely important from the perspective of a circular economy, which prioritizes the reuse and recovery of resources. In addition, agricultural production is growing worldwide and this has the consequence of increasing demand for fertilizers. By-products of the widely used anaerobic digestion (AnD) of sewage sludge, such as reject water, can also be used for nutrient recovery.

The aims of this study are: (i) to evaluate the efficiency of nitrogen and phosphorus recovery from the reject water using lime precipitation and (ii) to compare of the efficiency of this process using mono- and co-digestion reject water.

Materials and methods

The research was performed for samples of reject water from digestate dewatering taken from four large municipal wastewater treatment plants (a population equivalent of more than 100,000) located in Poland. One of the four wastewater treatment plants studied conducts sludge mono-digestion, while the others conduct co-digestion with waste from the agro-food industry. Basic information on sludge handling is summarised in Table 1.

Table 1 Basic informations of the material used for the anaerobic digestion in the studied WWTPs

The facility	WWTP 1	WWTP 2	WWTP 3	WWTP 4
the material used for the anaerobic digestion	primary and secondary sludge without the use of co-substrates	primary and secondary sludge with use of co-substrates (waste from the agri-food industry and external waste activated sludge)	primary and secondary sludge with use of co-substrates (fats from industrial plants	primary and secondary sludge with use of co-substrates (waste from the agri-food industry and external waste activated sludge)

The following parameters were determined in samples of raw reject water: ammonia nitrogen, total phosphorus (TP), orthophosphate (PO_4–P), chemical oxygen demand (COD), calcium and magnesium. Phosphorus and nitrogen removal from reject water was conducted in a laboratory model consisting of three 1 dm^3 reactors placed in a water bath. Each reactor was equipped with a mechanical stirrer and a pH probe. The studies were carried out using increasing dose of $Ca(OH)_2$ administered in the form of milk of lime. The pH was measured continuously, and in addition, samples were taken after 1h, 2h, 3h, 12h and 24h of the study. The ammonia nitrogen (NH_4-N), total phosphorus (TP), orthophosphate (PO_4–P), chemical oxygen demand (COD), calcium and magnesium were measured using a DR20000 spectrophotometer (Hach, GmbH, Germany). The pH was measured using a portable multi-parameter meter (WTW InoLab pH 720).

Results and Discussion

The reject water was characterized by high concentrations of phosphate phosphorus (over 270 mg PO_4-P/dm^3 in the case of WWTP 3 and over 230 mg PO_4-P/dm^3 in the case of WWTP 1), which accounted for more than 96% of total phosphorus. The lowest concentrations of ammonium nitrogen, Ca, COD and the lowest pH were observed in the reject water from WWTP 1 (mono-digestion). The highest concentrations of ammonium nitrogen were again recorded in WWTP 3 (more than 1500 mg NH_4-N/dm^3).

Phosphate precipitation using $Ca(OH)_2$ has proven to be a method that achieves very high removal efficiencies of up to 99.9%. The minimum reactant doses for which such efficiencies were achieved were

arranged as follows (the ratio of mg Ca to mg PO_4-P/dm^3 removed) :

WWTP 1 (10,8) < WWTP 2 (16,6) < WWTP 3 (18,0) < WWTP 4 (64,1)

This means that leachates from the dewatering of mono-fermentation sludge required by far the lowest doses of $Ca(OH)_2$, despite the relatively high initial concentrations of phosphate phosphorus. It is also worth noting that the process of phosphorus removal was rapid, and the maximum reduction was achieved after just 1 hour of the experiment. The process of ammonium nitrogen removal was different, in which the highest efficiencies were achieved for a time of 24 h. In this case, the lowest ammonium nitrogen removal efficiency was obtained for the mono-digestion reject water (WWTP1): only about 65% efficiency was obtained at a dose of 6.9 mg Ca to mg NH_4-N/dm^3 removed. The highest efficiency (85%) was observed for the WWTP 3 (dose of 3.6 mg Ca to mg NH_4-N/dm^3). However, the removal of ammonium nitrogen took place from the surface of the mechanically stirred reactors without assisting the process by blowing with air, so research on ammonium nitrogen removal should be further carried out.

Acknowledgements

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References

Campo G, Cerutti A, Lastella C, Leo A, Panepinto D, Zanetti M, Ruffino B. Production and Destination of Sewage Sludge in the Piemonte Region (Italy): The Results of a Survey for a Future Sustainable Management. Int J Environ Res Public Health. 2021 Mar 30;18(7):3556. doi: 10.3390/ijerph18073556. PMID: 33808114; PMCID: PMC8036911.

Statistic Poland. Environment 2022. Available online: https://stat.gov.pl/en/topics/environment-energy/environment/environment-2022,1,14.html (accessed on 5 June 2023).

Domini, M.; Bertanza, G.; Vahidzadeh, R.; Pedrazzani, R. Sewage Sludge Quality and Management for Circular Economy Opportunities in Lombardy. Appl. Sci. 2022, 12, 10391. https://doi.org/10.3390/app122010391

Bioprocess of Keratin wastes conversion into agronomic biostimulants and biofertilizer

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Keywords: Keratin, proteases, microbiology, biostimulant, biofertilizer and soil.

ABSTRACT

In the present work, a circular economy process of agro-industrial waste, specifically keratins from slaughterhouses, in agronomic/environmental biostimulants has been developed.

Keratin is a fibrous protein (96% protein) with a high organic nitrogen content, highly insoluble, rich in sulfur (McKittrick 2012), found in various animal tissues, such as feathers, hair, nails, and horns (Li, 2022)

It is an organic waste from highly polluting slaughterhouses, due to its low degradability, very resistant to attack with organic acids, alkaline solutions or normal enzymes such as pepsin or trypsin (Vidmar, 2018). It also presents a serious environmental problem due to its elimination in the form of dumping or incineration, thus increasing the concentration levels of greenhouse gases and therefore, it can negatively influence public health problems, so it is necessary to address this problem. growing environmental risk (Korniłłowicz-Kowalska, 2011).

Keratolytic residues may be susceptible to their revaluation and therefore reconvert them into value-added products for different applications in many fields (Kang 2018). One of the ways of valorization is its conversion into biostimulants and biofertilizers, they are products of high biological value whose use is increasing in current agriculture, because they are nutritional sources for soils and plants, they produce stimulation and regulate the physiological parameters of the plants as well as improvement in crop production (Tejada 2018).

The objective of this work has been to develop a bioprocess for the conversion of keratin residues into biostimulants and biofertilizers for use in agriculture.

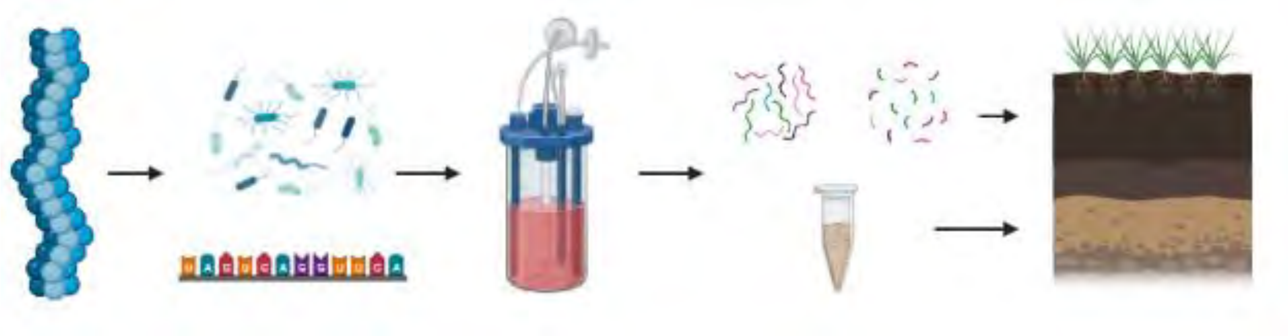
The production process is a fermentation using keratins as the only source of carbon and nitrogen, specifically those of pig bristles. The microorganisms used are keratinolytic bacteria. Different endemic strains of animal keratins not described as keratolytic have been isolated by 16S genetic sequencing analysis such as Bacillus Licheniformis, Sporosarcina Luteola and Bacillus Fordii. The proteolytic potential (keratinases) of the different isolated strains was evaluated, highlighting the greater potential for keratin degradation in S. luteola.

These strains are biofertilizers, because they present plant grothw prpomoting (PGPB). Thus, the three strains had the ability to form biofilms, while the B. Licheniformis strain solubilized siderophores and the B. Fordii strain was able to fix nitrogen. On the other hand, they are excretors of enzymes with biofertilizing activity with expression of DNase, lipase, cellulase, amylase, pectinase and protease.

CONCLUSION

A biostimulant was developed using a keratin medium, giving rise to an extract rich in peptides and amino acids with a molecular weight <300 da by 72%.

The biostimulant potential in soils was also evaluated by analyzing soil enzymatic activities, highlighting a stimulation in dehydrogenase, β-glucosidase and phosphatase activity. In conclusion, the final result is the conversion of keratins into soluble products, made up of protein hydrolysates (Biostimulants), enzymes (Biostimulant) and insoluble biomass (Biofertilizers).



Keratin | Sequencing endemical keratin bacteria (PGPB) | Fermentation | Biostimulant and biofertilizer: Peptides, aminoacids and biomass | Soil application (microbial stimulation)

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References:

Calin, M., Constantinescu-Aruxandei, D., Alexandrescu, E., Raut, I., Doni, M. B., Arsene, M.-L., et al. (2017). Degradation of keratin substrates by keratinolytic fungi. Electron. J. Biotechnol. 28, 101–112. doi: 10.1016/j.ejbt.2017.05.007

Korniłłowicz-Kowalska, T., and Bohacz, J. (2011). Biodegradation of keratin waste: theory and practical aspects. Waste Manag. 31, 1689–1701. doi: 10.1016/j.wasman.2011.03.024

McKittrick, J., Chen, PY, Bodde, SG, Yang, W., Novitskaya, EE y Meyers, MA (2012). The structure, functions and mechanical properties of keratin. JOM. 64, 449–468. doi: 10.1007/s11837-012-0302-8

Qingxin, L (2022). Perspectives on Converting Keratin-Containing Wastes Into Biofertilizers for Sustainable Agriculture. Frontiers of microbiotechnology. 13. Doi:3389/fmicb.2022.918262

Tejada Moral, M., Rodríguez Morgado, B., Paneque Macías, .I. y Parrado Rubio, J. (2018). Effects of foliar fertilization of a biostimulant obtained from chicken feathers on maize yield. European Journal of Agronomy, 2018 (96), 54-59.

Vidmar, B., and Vodovnik, M. (2018). Microbial keratinases: enzymes with promising biotechnological applications. Food Technol. Biotechnol. 56, 312–328. doi: 10.17113/ftb.56.03.18.5658

Possibilities of nutrients recovery from the liquid fraction of digestate from agricultural biogas plants in Poland.

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ABSTRACT

Introduction

Poland has a gigantic biogas potential, which, taking into account the use of energy crops as well, is estimated at more than 6.5 GW of capacity (Raport Biogaz w Polsce 2022). The fastest growing and promising branch of sustainable electricity and heat production, especially in agricultural areas, are agricultural biogas plants. There are currently 140 agricultural biogas plants in Poland, and their number is growing steadily year by year (Rejestr wytwórców biogazu rolniczego, 2023). Given the booming market for green hydrogen production, also biogas reforming to produce H_2, further growth in the number of biogas plants is expected. Especially since the hydrogen storage can become a worthy competitive option for electric energy storage and Poland has significant agricultural potential, ranking third in Europe in terms of the share of agricultural land in the country's total area (Kumar et al. 2022). An increase in the number of biogas plants also means an increase in waste production in the form of digestate. It provides valuable material containing large amounts of nutrients such as nitrogen and phosphorus. The liquid fraction of digestate from agricultural biogas plants, which accounts for up to 85% of the raw digestate by weight, contains high concentrations of nitrogen and phosphorus. (Vaneeckhaute et al., 2018). The supply of phosphorus as an agricultural input depends on the limited mineral reserve of phosphate and the primary reserves of this type of resources are located in Morocco, China or Russia (Smol 2021). Resource recovery is therefore becoming a necessity both for the security of the European fertilizer market and to fit in with the tenets of a circular economy. This is in line with EU documents: *Closing the loop-An EU action plan for the Circular Economy, the European Green Deal* and a strategic document indicating the most important areas of CE implementation in Poland *Roadmap Transformation towards a circular economy*. At the same time, the use of by-products of agricultural biogas plants enables the rational use of mineral and organic fertilizers is recommended as one of the ways to protect the soil environment and prevent eutrophication.

The aim of this study is to evaluate the efficiency of nitrogen and phosphorus recovery from the liquid fraction of digestate using lime precipitation.

Material and Methods

Digestate from agricultural biogas plant located in Poland, obtained from the fermentation of corn silage and cow manure was used. Fermentation tests were carried out during 28 days on a pilot scale stand located in municipal wastewater treatment plant. Anaerobic digestion reactor operating in a feedstock (non-flow) system was used. The share of inoculum (the sludge from fermentation chambers of agriculture biogas plant) in co-fermentation was approximately 80% and feedstock 20% (by volume). The digestate samples were subjected to mechanical separation into solid and liquid fraction. Separation of the fraction was carried out using a Hettich 320R laboratory centrifuge, with 4000 rpm (characteristic for the operation of industrial centrifuges) and time 30 min.

Phosphorus and ammonium nitrogen removal studies were conducted in a laboratory model consisting of three 1 dm^3 reactors placed in a water bath. Each reactor was equipped with a mechanical stirrer and a pH probe. Precipitation of phosphorus from reject water was carried out using various doses of $Ca(OH)_2$, ranging from 5500 to 7000 mg Ca/dm^3 administered in the form of milk of lime, which allowed the reject water to become alkaline enough for the process. The pH was measured continuously, and in addition, samples were taken after 1 h, 2 h, 3 h, 4h, 5h, 6h, 8h, 12 h and 24 h of the study. The ammonium nitrogen (N-NH4), total phosphorus (TP), orthophosphate (P-PO4), chemical oxygen demand (COD), calcium and magnesium were measured using a DR20000 spectrophotometer (Hach Company, Loveland, Colorado, USA). The pH was measured using a portable multi-parameter meter (WTW InoLab pH 720).

Results and Discussion

The ammonium nitrogen in liquid fraction of digestates was detected above 1700 mg NH_4-N/dm^3. The concentration of organic substance expressed as COD ranged from 5900 to 7600 mg O_2/dm^3. Phosphate phosphorus concentrations accounted for about 75% of total phosphorus and were over 50mg PO_4-P/dm^3. The highest nutrient removal efficiency was found at a dose of 7000 mg Ca/dm^3 (reaction time 12 h, pH=12.1), it was: phosphorus precipitation efficiency 97%, and nitrogen removal 99%. Lower pH values resulted in significantly lower process efficiency (maximum 74% and 78% pH=9.9, respectively). For the lowest applied dose of $Ca(OH)_2$, a decrease in pH was observed during the experiments, probably due to the consumption of lime for phosphate precipitation.

Conclusion

The very high efficiency of nutrient removal using a well-known and readily available reagent such as milk of lime is a promising research direction for nutrient recovery from liquid by-products of agricultural biogas plants.

Acknowledgements

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References

Raport Biogaz w Polsce 2022, www.magazynbiomasa.pl (in Polish)

https://www.gov.pl/web/kowr/rejestr-wytworcow-biogazu-rolniczego

Kumar R., Kumar A., Pal A. Overview of hydrogen production from biogas reforming: Technological advancement,International Journal of Hydrogen Energy 2022, 47, 34831-34855, https://doi.org/10.1016/j.ijhydene.2022.08.059

Vaneeckhaute C., Belia E., Meers E., Tack F.M.G., Vanrolleghem P.A. Nutrient recovery from digested waste: Towards a generic roadmap for setting up an optimal treatment train,Waste Management 2018, 78, 385-392, https://doi.org/10.1016/j.wasman.2018.05.047

Smol, M. Transition to Circular Economy in the Fertilizer Sector—Analysis of Recommended Directions and End-Users' Perception of Waste-Based Products in Poland. Energies 2021, 14, 4312. https://doi.org/10.3390/en14144312

Remote sensing indicators for the study of drylands in Mediterranean climate

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Keywords: land restoration monitoring, Sentinel-2, Landsat-8, Sustainable Development Goals

ABSTRACT

Landscape degradation and potential desertification hampers ecosystem's services sustainability, becoming a substantial environmental and societal problem at a global scale. The aims of this work is to identify and test indicators based on both Remote Sensing (RS) satellite images and field-based data, in order to monitor the restoration of degraded landscapes. These indicators, which describe land cover and vegetation status, can represent a great potential to improve desertification assessment by providing support for the monitoring and management of ecological restoration processes through Nature-Based Solutions (NBS), as stated in the Good Practice Guidance document by UNCCD (SDG Indicator 15.3.1, 2021).

One of these indicators, Land Cover (LC) changes, has been carried out to analyse the evolution of landscape over different years. LC maps have been generated by automatic classification processes of images obtained from Landsat series satellites (mainly Landsat-5/7/8) for the years 2005-2014, through their Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+), Operational Land Imager (OLI) and Multispectral Imager (MSI) sensors. Maps have been generated from 2017 to 2021 using Sentinel-2A and 2B data. These images, as well as vegetation and moisture indices, have been classified using the k-Nearest Neighbour (kNN) algorithm (González-Guerrero et al., 2020) to obtain a map with 5-6 categories. For the training of the classifier and the subsequent validation of the output map, a set of training areas collected by visual interpretation of the available orthophotos was considered (Congalton and Kass, 2009). For the validation of the 2021 LC map output, test areas were used to generate a confusion matrix to evaluate the classification result.

The work presented here is part of a larger EU funded project, more specifically the "LIFE20 PRE/IT/000007 - NewLife4Drylands" project, which includes a total of six study areas located in the Southern European region. Here we focus on testing the different indicators at three out of these six areas: "El Bruc" and "El Nublo-Tamadaba", both affected by forest fires in 2015 and 2019, respectively, and "Asterousia Mountains" located in the south of the island of Crete, Greece. "El Bruc" is located in the Catalan region (NE of the Iberian Peninsula, Spain) next to the Natural Park of Montserrat (Natura 2000 Network). The area is characterised by a dry sub-humid climate with recurrent forest fires. This area has been affected by rural abandonment since the beginning of the 19th century, which has led to an expansion of scrubland and forest, mainly Aleppo pine (*Pinus halepensis*), which in turn increases the risk of large forest fires. "El Nublo-Tamadaba" is a dryland with increasing desertification, located in the island of Gran Canaria (Canary Islands, Spain) between the Natural Park of El Nublo and Tamadaba (in Natura 2000 Network). At this site, desertification processes are aggravated by the decrease in rainfall, recurrent forest fires and herbivory caused by the abundant presence of wild goats. Finally, the climatic conditions of the "Asterousia" area, with long, dry summers and high evapotranspiration rates, favour conditions for desertification. In addition, the loss of productive and arable land through soil erosion and degradation, overexploitation of aquifers, and overgrazing by animals are some of the key factors that pose a desertification risk to the site, which is then further intensified by the current rise in temperatures in the Mediterranean area.

In this study we present quantitative and qualitative results based on the indicators tested for three different sites, including LC maps, vegetation indices, burned area intensity, among others (Figure 1). These results allow a detailed monitoring and assessment of degradation and recovery processes in each study area during the time period for which satellite data are available.

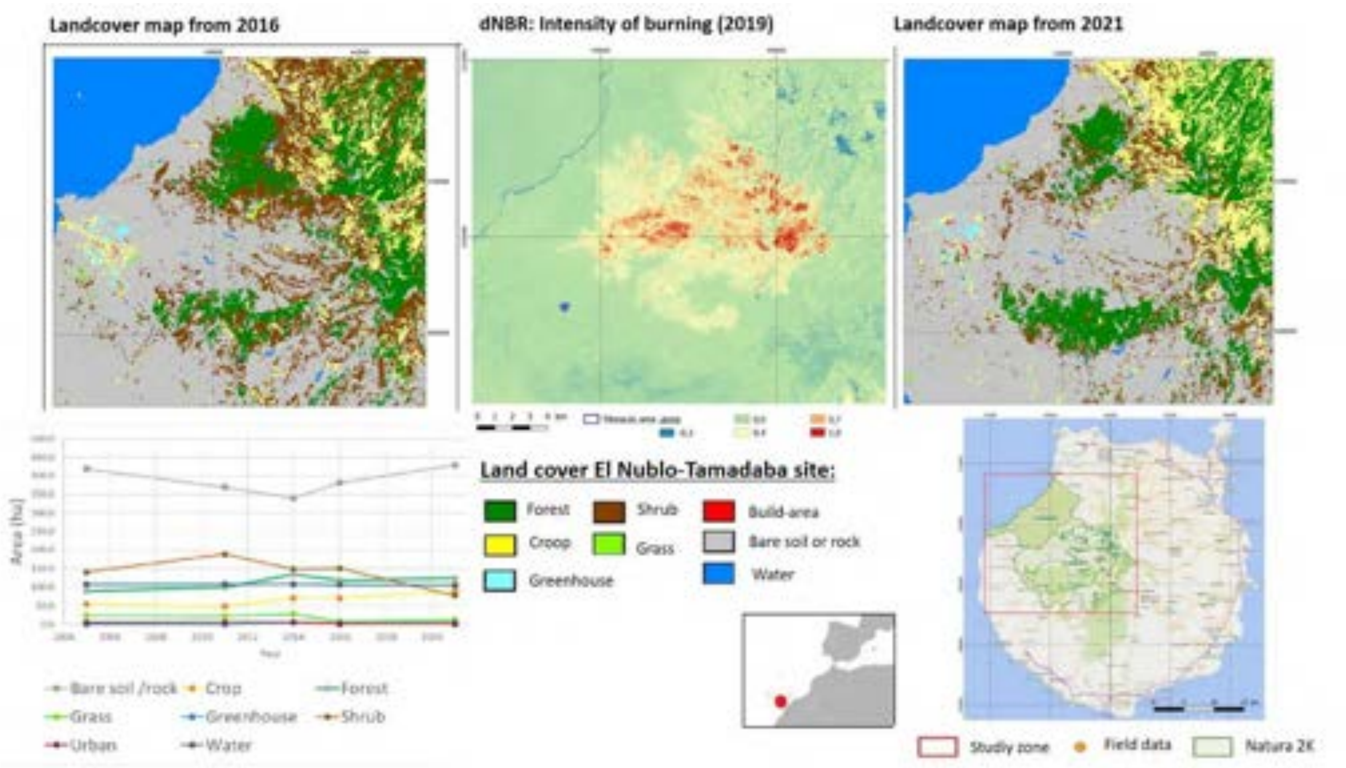

Figure 1. Example of a LC map made for the years 2016 and 2021 for El Nublo and Tamadaba area. Middle image represents the burn intensity of the 2019 fire.

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References:

Congalton, R.G.; Kass, G. (2009). Assessing the Accuracy of Remotely Sensed Data: Principle and Practices, 2nd ed.; Taylor & Francis Group: Abingdon, UK, 2009; ISBN 9781420055122.

González-Guerrero, O.; Pons, X.; Bassols-Morey, R.; Camps Fernández, F.X. (2019). Dinàmica de les superfícies de conreu a Catalunya mitjançant teledetecció en el període 1987-2012. Revista Quaderns Agraris, 46, 59-91. https://raco.cat/index.php/QuadernsAgraris/article/view/359167

ICGC (2021). Mapa topogràfic de Catalunya 1:50.000. Available in: https://www.icgc.cat/Administracio-i-empresa/Descarregues/Cartografia-topografica/Mapa-topografic-1-50.000

SDG 15.3.1. (2021). Version 2.0 – Good Practice Guidance. SDG Indicator 15.3.1, Proportion of Land That Is Degraded Over Total Land Area. Available online on 29 September 2021 from: https://www.unccd.int/publications/good-practice-guidance-sdg-indicator-1531-proportion-land-degraded-over-total-land

Be Well and Green When Digital - Lessons Learnt from the BeWEEN project

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Keywords: Digital Competencies, Digital Safety, Digital Sustainability, Digital Transformation, Education, Circular Economy

ABSTRACT

Societies are becoming more and more dependent on digital technologies, as digital devices are becoming an integral part of our lives and the vast majority of people seem to be extremely attached to their smartphones and laptops. Digital devices are part of our everyday life, from work to our free-time activities and even while we rest or sleep. Furthermore, the pandemic of COVID-19 has been described as an accelerator regarding our reliance on digital technologies and led to a more than ever digitized world. As a result, digitalization which enables a variety of processes by leveraging digital technologies didn't come as a surprise and like every breakthrough that is accompanied by both advantages and disadvantages, this one is no exception. In this context, it is crucial not to ignore our health or the impact the tech we use has on the environment. It is essential for the youth to be fully aware of the environmental and the psychological well-being risks that we often neglect, to be able to resolve different tasks and problems, guide others, and apply knowledge independently. However, the switch to digital classrooms (online/distance classrooms) added considerable workload and challenges to teachers who struggle to deliver the curriculum online, thus oftentimes leaving the "Safety" aspects in the tail of their To Do list due to time constraints and lack of competence and knowledge on the subject. Even in the hybrid scheme (blended on-site and online learning) currently adopted by most countries, the conditions do not allow for proper pedagogical design and implementation of a complete training on healthier and greener use of digital devices in frames of national curricula.

This paper presents the effort of a transnational Partnership for Digital Education Readiness to build capacity in healthier, 'greener' and more responsible use of digital technology. The 'Be Well and Green when Digital' (BEWEEN) project aims to develop competences of proficiency levels up to 7 and promote "smart habits" for tech-smart teachers and students. Training material is designed in alignment with the Competences 4.3 "Protecting health and well-being" and 4.4 "Protecting the environment ", from Area 4 "Safety" of the EU Digital Competence Framework (DigComp). DigComp has been used as a tool by a number of organisations to develop learning materials, in most cases however not in its entirety, but focusing on a selected sub-set of competence areas and competences. The main objective of the proposed approach is to develop and test learning tools which will empower high school teachers and students against health- and environmental- risks and threats through meaningful and comprehensive formal and informal education. The thorough observation of the aforementioned risks that stem from digitalization has triggered the need to help the educators gain some perspective about the emerging digital devices and teach their students how to recognize the environmental and psychological impacts of digital technologies and their use, as well as accumulate teaching resources that promote the adoption of ''green'' habits. BeWEEN aims to help European school communities to understand the implications of digitalization and adopt behaviours aligned with digital maturity principles. In cooperation with dozens of teachers from four different countries, the project's partners developed a curriculum consisted of two discrete modules: a) Protecting Health and Well-being and b) Protecting the Environment. The teachers took also part in multiple workshops under the guidance of the project's academics, in order to dynamically finalize the teaching resources that will be utilized for teaching in classrooms and are one of the main results of the project.

Objective of the project is to provide resources to teachers, in order to educate their young students about the new opportunities that digital devices can provide and at the same time inform them about the environmental and psychological risks that we often tend to neglect. The expected results of the project are both tangible re-usable outputs/tools for teachers and students as well as increased teachers' competence and skills required for distance teaching. Project's outcome includes learning material, guidelines, tools, a dedicated LMS platform and a gamified mobile application, targeted to high school students, but suitable for all ages including children, parents and teachers. The application's design provides a fun learning experience, but also upgrades the learning curve in terms of how digitalization affects well-being and environment. Especially, in terms of protecting the environment, the principles of circular economy lie in the epicentre of the project's results. Among others, teachers and students using the BeWEEN tools will be able to learn how to: balance the use of digital technologies, recognize environmental and psychological impacts of digital technologies and their use, adopt ''green'' habits/behaviours, apply efficient strategies for protecting their well-being and the environment, overcome the challenges that arise from digitalization in almost all aspects of modern lives, enhance their digital skills and finally, buy, use and dispose digital devices responsibly.

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Enhancing methane mitigation in landfills: insights from biocover composition and microbial parameters

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Keywords: biocover, landfills, landfill mining, methane oxidation

ABSTRACT

The escalating volume of solid waste being dumped into landfills is a growing global concern. Approximately 40% of waste worldwide is currently disposed of in landfills, significantly contributing to anthropogenic methane (CH4) emissions. Methane, a potent greenhouse gas, is generated through the anaerobic microbial degradation of the organic fraction of waste in landfills. To address the economic and environmental challenges associated with waste disposal, dynamic landfill management, and methane-oxidation systems, such as biocovers, have been proposed as cost-effective alternatives to mitigate methane emissions. Biocovers utilize various materials obtained from landfill waste and leverage the activity of methanotrophic bacteria to facilitate methane oxidation. However, the methane oxidation potential of these materials and the performance of biocovers at the field scale have not been extensively studied.

This study investigated the genetic potential for methane oxidation in biocovers composed of different materials obtained from landfill waste and operating at field conditions. The study sites included three landfills: the Kudjape landfill, which was closed in 2009, and the Uikala and Tallinn landfills. The Kudjape landfill featured a biocover composed of the fine fraction (<40 mm) of material obtained from landfill mining, mixed with matured sewage sludge compost and local soil (Kriipsalu et al., 2023). The Uikala landfill had two experimental sites with biocovers of different thicknesses and fraction sizes of mechanically biologically treated waste (MBT). Similarly, the Tallinn landfill had two sites with varying thicknesses of MBT layers. Gas monitoring wells were installed at all sites to facilitate data collection.

Sampling involved opening the biocover adjacent to the gas monitoring wells, and composite samples were collected from different layers of the biocovers at each site. The DNA was extracted from the samples, and quantitative PCR (qPCR) was used to evaluate bacterial abundance by targeting the 16S rRNA gene and to assess the genetic methane oxidation potential by targeting the membrane-bound particulate methane monooxygenase encoding gene (pmoA).

The study results revealed that the structure and composition of the biocovers significantly influenced bacterial abundance, methanotrophic potential, and the spatial distribution of methanotrophs within the biocovers. The quantity of pmoA, an indicator of methane oxidation potential, was highest in the upper 25 cm layer of the biocover composed of landfill mining material (Kudjape). The fraction size of the mechanically biologically treated waste (MBT) materials also affected pmoA abundance, with larger particle sizes resulting in higher quantity. Additionally, a thicker layer of MBT in the Tallinn landfill favored a greater proportion of methane degraders within the bacterial community.

The study outcome highlights the importance of material composition and field conditions in influencing the genetic potential for methane oxidation in landfill biocovers. The findings provide insights into optimizing biocover design and composition to enhance methane mitigation in landfills.

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References:

Kriipsalu, M., Somani, M., Pehme, K., Tamm, O., Truu, J., Truu, M., & Orupold, K. (2023). Performance of biocover in controlling methane emissions from landfill: A decade of full-scale investigation. *Process Safety and Environmental Protection*, *172*, 486–495.

Proposal of a multicriteria decision making method to support the selection of nature-based solutions addressing rainwater management

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Keywords: Nature-based solutions, rainwater, multicriteria decision-making, TOPSIS

ABSTRACT

Introduction

Nature based solutions (NBS) are considered one of the main alternatives to support green transition in the urban space and built environment. Swales, infiltration trench, raingarden, permeable pavement, green roofs, green walls, local reservoirs, are only some of the alternatives available to enable at the same time a greener city and prevent flash flooding events. This diversity of alternatives on the one hand enables engineers to provide solutions for several different situations, but on the other hand the choice of the best solution for the case studymust be carefully defined. So, in this context, the present study aims to contribute to the development of a multicriteria decision-making tool to support the choice of nature-based solutions to support rainwater management.

Material and methods

In terms of mathematical formulation, it was used the multicriteria method called Technique for Order Preference by Similarity (TOPSIS), was developed by Hwang & Yoon (1981). In this method, which is based on the Euclidean Distance, the alternative with the best performance is the one that presents the smallest distance from the Ideal solution or the greatest distance from the Nadir solution depending on the adopted approach (HUANG et al., 2011).

$$r_{ij} = \frac{f_{ij}}{\sum_{j=1}^{j} f_{ij}}; i = 1, \ldots, n; j = 1, \ldots, J$$

$$v_{ij} = w_i r_{ij}; i = 1, \ldots, n; j = 1, \ldots, J$$

$$D_j^* = \sqrt{\sum_{i=1}^{n} \left(v_{ij} - v_i^*\right)^2}, j = 1, \ldots, J$$

$$D_j^- = \sqrt{\sum_{i=1}^{n} \left(v_{ij} - v_i^-\right)^2}, j = 1, \ldots, J$$

$$C_j^* = \frac{D_j^-}{D_j^* + D_j^-}, j = 1, \ldots, J$$

Where n is the number of indicators, *J* is the number of evaluated alternatives, f_{ij} is the value of the i^{th} indicator for the j^{th} alternative considered and r_{ij} is the value of the respective normalized indicator, wi is the weight of the i^{th} indicator and v_{ij} is the value of the i^{th} indicator normalized and weighted for the j^{th} alternative, vi- corresponds to the ideal value of the i^{th} normalized and weighted indicator, vi- corresponds to the nadir value of the i^{th} normalized and weighted indicator, D_j* and D_j are respectively the distances from the analyzed alternative to the Ideal and Nadir solution. The alternatives are ranked in descending order of Cj*, that is, the higher the value of the latter, the better the classification of the respective alternative. The criteria that were included to compare the NBS were chosen based on Brito (2006), as presented in Table 1. To validate the proposed method a case study based on data provided by

Vasconcelos (2014). Six scenarios were compared, 1 base scenario with a conventional drainage system and 5 alternative scenarios using different NBS, according to Table 2.

Table 1 - Evaluation criteria used in the multicriteria analysis model (BRITO, 2006).

Criteria	Indicator
Physical change	Permeable areas
Environmental impact	Green area
Water quality	Water pollutants
Peak time increase	Peak time
Peak flow reduction	Peak flow
Circularity	Rainwater harvesting and use
Economic impact	Costs

Table 2: Description of the comparison scenarios for the subdivision studied and respective characterization data (VASCONCELOS, 2014).

Scenario	Solution	Description
Base	Conventional drainage	Pipe drainage system
1	Reservoir	Water reservoir 11,5 m³
2	Swale	Swale 180 m² and permeability 1.10^{-7} m/s
3	Green roof	Greenroof 150 m²
4	Permeable pavement	Sidewalk with 60 m² of permeable pavement with 1260 m²
5	Raingarden	Raingarden 180 m²

Results and discussion

Table 3 presents the results according to the TOPSIS method, as well as the classification of the alternatives. It is worth highlighting that the alternative in the last position was the base scenario, which was expected since this alternative does not correspond to a NBS solution, it indicates the capability of the model to depict features that enable to characterize NBS for water management. The first position was got by raingarden, followed by swale and green roofs, both in the second position.

Table 3: TOPSIS scores and classification of scenarios.

Scenario	Description	Topsis score	Ranking
Base	Conventional drainage	0.29	5th
1	Reservoir	0.44	6th
2	Swale	0.55	2nd
3	Green roof	0.55	2nd
4	Permeable pavement	0.46	3th
5	Raingarden	0.58	1st

Conclusions

This paper provided a multicriteria decision-making to support the selection of NBS for rainwater sustainable management based on TOPSIS model. The model was applied in a case study that showed the efficacity of the developed tool in facilitating the choice of the solution, proving to be a useful instrument.

References:

BRITO, D. S. Metodologia para definição de sistemas de drenagem. UNB, Dissertação de Mestrado, 2006, 131p.

COELHO, L. M. G. HENRIQUES, R. S. (2017). "Proposta de modelo de análise multicritério aplicada ao apoio a seleção de técnicas compensatórias". XI Encontro Nacional de Águas Urbanas, Belo Horizonte.

HWANG, C. L.; YOON, K. Multi attribute decision making: methods and applications, New York, USA: Springer-Verlag, pp. 37-48, 1981.

HUANG, I. B.; KEISLER, J.; LINKOV, I. Multi-criteria decision analysis in environmental sciences: Ten years of applications and trends. Science of the total environment, 409, 3578-3594, 2011.

VASCONCELOS, A. F.. Estudo e proposição de critérios de projeto para implantação de técnicas compensatórias em drenagem urbana para controle de escoamentos na fonte. Dissertação (mestrado) – UFRJ. Rio de Janeiro. 2014, 192p.

New generation Christmas tree shape hybrid treatment wetland for wastewater treatment in Roztocze National Park, Poland

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Keywords: hybrid treatment wetland, protected area, efficient wastewater treatment, biogenic compounds

ABSTRACT

This paper presents the results of a study on the efficiency and reliability of pollutants removal from domestic wastewater in a hybrid constructed wetland wastewater treatment plant in Kosobudy. The facility is located next to the official buildings of the Roztocze National Park (RNP) in Poland. The treatment plant was built in 2014 and is used to dispose of domestic wastewater from three buildings: two forester's lodges and an administration building. It serves about 20 people – residents and employees of the RNP. The designed capacity of the treatment plant is 2.0 $m^3 \cdot d^{-1}$. The treatment plant has a shape of a Christmas tree (figure 1). It consists of a three-chamber settling tank with a pumping station with an active capacity of 8 m^3, a system of three constructed wetland beds (VF-HF-HF) with *Glyceria maxima, Phragmites australis* and *Salix viminalis*. The area of each constructed wetland bed is 60 m^2. The recipient of treated wastewater is an infiltration pond.

Figure 1. The hybrid constructed wetland wastewater treatment plant in the shape of a Christmas tree in the Roztocze National Park (Poland)

The study of the treatment plant was conducted from 2016 to 2020. During this period, physico-chemical analyses were carried out. They concerned both the influent flowing into the treatment plant and the treated effluent flowing out of the subsequent stages of treatment: settling tank, VF-type bed with *Glyceria maxima*, HF-type bed with *Phragmites australis* and HF-type bed with *Salix viminalis*. In each year, samples for the study were taken seasonally, in winter (February), spring (May), summer (August) and autumn (November). A total of 20 measurement series were carried out within which organic matter (BOD_5, COD), total suspended solids, total nitrogen and total phosphorus were determined in the wastewater samples. On the basis of the obtained results, the technological efficiency and reliability of the

studied facility in investigated operation period were determined. The reliability of system operation was determined using the Weibull method.

The facility's average hydraulic load, determined based on water consumption readings from water meters installed in buildings served by the treatment plant was during the study period from about 1 to 1.47 $m^3 \cdot d^{-1}$. During the initial study period, the actual wastewater inflow to the treatment plant was close to the hydraulic load value assumed in the design (2.0 $m^3 \cdot d^{-1}$).

The average efficiency of BOD_5, COD and total suspended solids removal at the wastewater treatment plant in Kosobudy was 99.0%, 97.6% and 95.6%, respectively (Table 1). The degree of these indicators elimination in the settling tank was low, ranging from 20% for COD to 35% for TSS. The most favourable conditions for the mineralization of organic pollutants expressed in terms of BOD_5 and COD indices were found in the bed with vertical flow of wastewater with Glyceria maxima. This is indicated by the cumulative treatment effects in the settling tank and VF bed, which amounted to 97.7% for BOD_5 and 94% for COD. This may have been influenced by favourable aerobic conditions as a result of sewage aeration. The average values of pollutants in the effluent from the treatment plant measured by the BOD_5, COD and TSS indices were significantly lower than the maximum values allowed by the applicable legislation.

Table 1. Composition of raw and treated wastewater and efficiency of pollutants removal at the treatment plant in Kosobudy during 2016-2020

Parameters	Inflow			Outflow			Efficiency [%]		
	min	max	$\bar{x}$	min	max	$\bar{x}$	min	max	$\bar{x}$
Total suspended solids [mg/l]	89	576	271	2.2	46.8	10.6	76.9	99.1	95.6
BOD_5 [mg O_2/l]	136	651	383.4	0.2	13.6	3.7	90.0	99.5	99,0
COD [mg O_2/l]	310	1862	958.4	2	51	23	83.5	99.8	97.6
Total nitrogen [mg/l]	10	142	100	1.7	62	22.4	-50.0	98.4	77.6
Total phosphorus [mg/l]	12.9	27.8	17.2	0	6	1.4	53.5	99.8	92.1

Explanations: min – minimum; max – maximum; $\bar{x}$ – average.

The wastewater treatment plant in Kosobudy showed only a bit lower efficiency in the removal of nutrients. The average removal effects for total nitrogen were 77.6%, and for total phosphorus – 92.1%. The contribution of individual subsurface beds to the removal of biogenic compounds was more evenly distributed than in the case of organic pollutants. This was related to the lower efficiency of the VF bed, which provides good conditions for nitrification, but does not promote the reduction of nitrogen to molecular form. Meanwhile, the HF beds with *Phragmites australis* and *Salix viminalis*, due to the wastewater flow regime and the prevailing hypoxic conditions, created favourable conditions for the occurrence of denitrification processes and the ultimate removal of nitrogen in gaseous form. In the case of phosphorus, the filling of the beds may have played a greater role in its elimination. Seasonal conditions had little effect on the efficiency of wastewater treatment. It was most pronounced for total nitrogen.

The reliability of the treatment plant in Kosobudy in terms of removal of organic pollutants (BOD_5, COD) and TSS was closed to 100%. This is equivalent to a 100% probability of obtaining values of indicators below the standard in treated wastewater. These results confirm that the wastewater treatment plant is operating faultlessly and, with an operator risk of $\alpha = 0.05$ throughout the year, guarantees a positive passing of control procedures for the mentioned indicators. Technological reliability for total nitrogen removal was 73%. The obtained reliability level indicates that for 99 days of the year, the facility did not ensure that the concentration of total nitrogen in treated wastewater was lower than permissible. The probability that the concentration of total phosphorus in treated wastewater would reach a value lower than the standard one was 96%.

The Christmas tree-shaped hybrid constructed wetland wastewater treatment plant is an effective solution for wastewater treatment and environmental protection in the Roztocze National

Park area. A 5-year study showed that constructed wetland systems can have an unusual shape and this does not reduce the effects of pollutants removal. This system can be an example of a new generation wastewater treatment plant.

Optimized removal of silica during manure treatment by electrocoagulation-flotation (EC-F) in view of fouling prevention of reverse osmosis membranes

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Keywords: Silica removal, Electrocoagulation-flotation, Fouling prevention, Wastewater treatment, Water reuse.

ABSTRACT

Nowadays, a large amounts of manure is produced which can lead to soil, surface water, groundwater and air pollution (Masse et al., 2007). However, rather than as a disposable waste, manure is also a useful resource as a part of environmentally friendly agriculture (Masse et al., 2007). Valuable nutrients, such as nitrogen, phosphorus, and potassium could extract from manure to create nutrient-rich fertilizers. On the other hands, instead of discharging manure as waste, treated manure wastewater can be used for non-potable purpose to reducing the demand for freshwater. Both fertilizer recovery and water reuse contribute to the circularity and sustainability of the agricultural sector while minimizing waste and conserving resources. As such, the continuous increase in environmental burden and the urgent need for resource recovery are setting a higher standard for manure treatment.

Manure is typically treated with aerobic activated sludge (Bicudo et al., 2000). As a final polishing step for this treatment, reverse osmosis (RO) membrane filtration is one of the most promising technologies. Selective reverse osmosis membranes can provide high-quality water for reuse (Vourch et al., 2008). However, one of the largest problems related to this membrane process is the fouling and scaling of the RO membrane. In this regard, silica (SiO_2) is commonly regarded as one of the major scalants responsible for the inorganic fouling of membrane surfaces (Cheng et al., 2009). Eventually, silica fouling causes performance degradation such as permeability loss, reduced recovery rate and premature system failure (Lisitsin et al., 2005).

The electrocoagulation-flotation (EC-F) process is a sustainable alternative treatment technology for removing a wide range of contaminants from various types of wastewater (Al-Raad and Hanafiah, 2021; López-Guzmán et al., 2021). EC-F is especially efficient in removing colloidal silica because of its strong negative charges (Den et al., 2006; Den and Huang, 2005). Specifically for electrocoagulation with aluminium anodes, the formation of stable hydroxyl aluminosilicates (HAS) has already been recognized as an important process of silica stabilization (Exley and Birchall, 1993).

This study examines the removal of silica during manure treatment by EC-F. The operational parameters (applied current density, electrolysis time, and initial pH) of the EC-F process (using an Al electrode) were optimised using an Response Surface Methodology (RSM) in view of effective manure (pre-)treatment, with a focus on maximum silica removal efficiency and minimum operational cost. In this experiment, manure was sampled from the inlet of the RO membrane system in a manure processing company located

in Langemark-Poelkapelle, Belgium. A tubular EC-F reactor was used with a novel design, in which the electrolytic cell (EC) comprises two concentric tubular electrodes that are vertically positioned (Parmentier et al., 2020). Removal of Silica, Total chemical oxygen demand (tCOD), soluble COD (sCOD), ammonium (NH_4^+-N), total nitrogen (TN) and total phosphorus (TP) was monitored. An RO scaling test and SEM-EDX spectroscopic analyses were performed to elucidate the effect of silica removal. A detailed membrane filtration test can be found elsewhere (Sauchelli Toran et al., 2020). The fouling potential (kf) was calculated using the slope of the incremental resistance vs. total permeate volume plot (Melián-Martel et al., 2018). In addition, the operational expenses (OPEX) of the ECF technology were calculated.

The RSM results indicate that the EC-F process is effective for removing silica responsible for scale formation on RO systems. A silica removal efficiency of 88% and an OPEX of 0.48 €/m^3 were achieved using an Al-electrode at a pH of 8.2 (non-adjusted manure pH), a current density of 16 mA/cm^2 and an electrolysis time of 23 s. The general parameters of untreated and EC-F pretreated manure is shown in table 1.

Table 1. General parameters of untreated and EC-F pretreated manure

manure	SiO_2(mg/L)	COD (mg/L)	TP (mg/L)	TN (mg/L)
untreated	104	1637	10.5	280
EC-F pretreated	13	1456	3.3	211

To verify if EC-F pretreatment of silica-containing manure can effectively reduce the fouling issues caused by silica precipitation, membrane filtration experiments with untreated manure and EC-F pretreated manure were carried out using the optimum operational parameter settings (pH=8.2, current density=16 mA/cm^2, electrolysis time=23 s). The residual silica content in the pretreated manure was around 12.7 mg/L, in accordance with a removal efficiency of +/- 88% as the initial concentration is 104 ± 35 mg/L. Figure 1 depicts the normalized flux (J/J_0) data as a function of time for untreated and pretreated manure produced by the EC-F pretreatment. For untreated manure, permeate flux began to decline as soon as membrane filtration started. As to EC-F pretreated manure, the flux only began to decline after 30 minutes of filtration. Fouling was the most common cause of flux drop (Melián-Martel et al., 2018). This observation, combined with the silica removal discussed above, demonstrates that minimizing the silica concentration may indeed be able to prevent some RO membrane fouling. Fouling potential is an indicator of the amount of foulant in the feedwater and as such demonstrate the relationship between fouling potential and silica concentration. The fouling potential (k_f) in this study decreased by 28% from 7.11×10^{16} to 5.10×10^{16} Pa s/m^2 after EC-F pretreatment, indicating an efficient foulant removal.

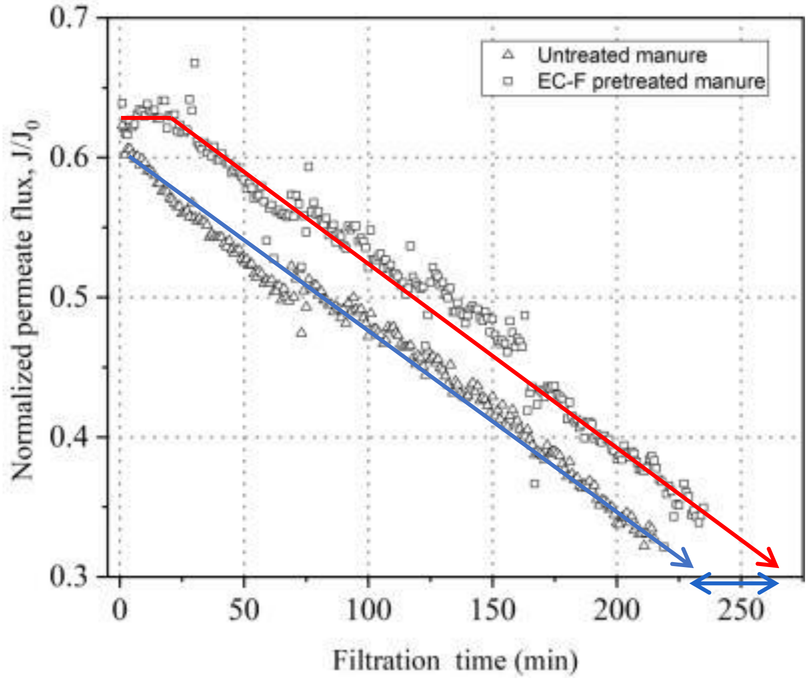

Figure 1. Normalized permeate flux for untreated and EC-F treated manure. The normalized flux corresponds to the permeate flux (J) at any time *t*, divided by the initial permeate flux of the membrane (J_0). EC-F was carried out under the following conditions: pH=8.2, current density=16 mA/cm^2, electrolysis time=23 s.

After the fouling tests, the membrane samples were inspected using the SEM-EDX method to observe the surface morphologies of RO membranes and detailed elemental analysis from the outer surfaces of fouled RO membranes. Figure 2 displays the SEM micrographs of two fouled RO membrane samples. The membrane surface was fully covered with particles after silica scaling by untreated manure as shown in Figure 2a, whereas the membrane surface was only partially covered by a scaling layer when the feedstream is ECF pretreated manure (Figure 2b). The EDX spectrum shows the presence of 0.40 atomic% Si accumulated on the outer surfaces of RO membranes after untreated manure was filtered, however this value decreased to 0.04 atomic% when ECF pretreated manure was applied.

As such, it can be concluded that EC-F pretreatment utilizing an Al-electrode is a promising technology for removing silica from manure to mitigate the fouling of RO membranes. EC-F technology extends the lifespan of RO membranes, thereby reducing the cost of manure treatment and further promoting water reuse.

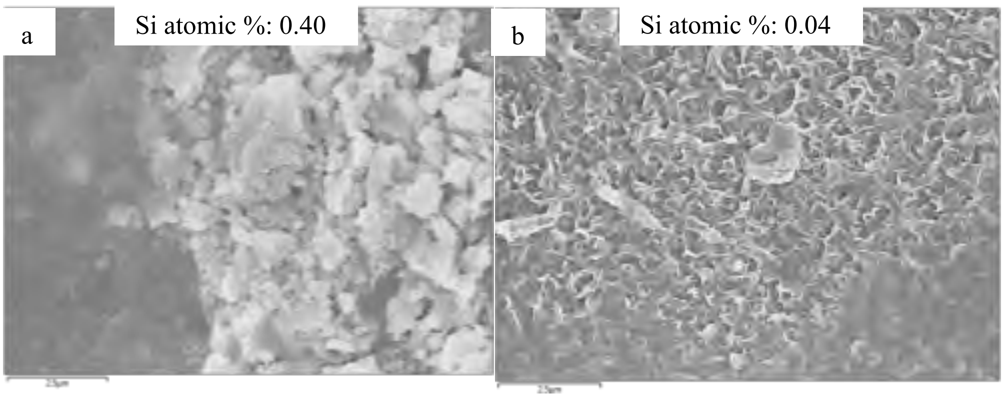

Figure 2. SEM-EDX images of the RO membrane surfaces using (a) untreated manure, and (b) EC-F pretreated manure.

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References:

Al-Raad, A.A., Hanafiah, M.M., 2021. Removal of inorganic pollutants using electrocoagulation technology: A review of emerging applications and mechanisms. J. Environ. Manage. 300, 113696. https://doi.org/10.1016/J.JENVMAN.2021.113696

Bicudo, J.R., Westerman, P.W., Oleszkiewicz, J.A., 2000. ANAEROBIC AND AEROBIC TREATMENT OF ANIMAL MANURE – A REVIEW. Proc. Water Environ. Fed. 2000, 495–530. https://doi.org/10.2175/193864700784995000

Cheng, H.H., Chen, S.S., Yang, S.R., 2009. In-line coagulation/ultrafiltration for silica removal from brackish water as RO membrane pretreatment. Sep. Purif. Technol. 70, 112–117. https://doi.org/10.1016/j.seppur.2009.09.001

Den, W., Huang, C., 2005. Electrocoagulation for removal of silica nano-particles from chemical-mechanical-planarization wastewater. Colloids Surfaces A Physicochem. Eng. Asp. 254, 81–89. https://doi.org/10.1016/j.colsurfa.2004.11.026

Den, W., Huang, C., Ke, H.C., 2006. Mechanistic study on the continuous flow electrocoagulation of silica nanoparticles from polishing wastewater. Ind. Eng. Chem. Res. 45, 3644–3651. https://doi.org/10.1021/ie0514410

Exley, C., Birchall, J.D., 1993. A mechanism of hydroxyaluminosilicate formation. Polyhedron 12, 1007–1017. https://doi.org/10.1016/S0277-5387(00)87177-6

Lisitsin, D., Hasson, D., Semiat, R., 2005. Critical flux detection in a silica scaling RO system. Desalination 186, 311–318. https://doi.org/10.1016/j.desal.2005.06.007

López-Guzmán, M., Flores-Hidalgo, M.A., Reynoso-Cuevas, L., Alberto Flores-Hidalgo, M., Reynoso-Cuevas, L., Khamis, M., Wait, I., Nenov, V., 2021. Electrocoagulation process: An approach to continuous processes, reactors design, pharmaceuticals removal, and hybrid systems—a review. Processes 9, 1831. https://doi.org/10.3390/pr9101831

Masse, L., Massé, D.I., Pellerin, Y., 2007. The use of membranes for the treatment of manure: a critical literature review. Biosyst. Eng. 98, 371–380. https://doi.org/10.1016/j.biosystemseng.2007.09.003

Parmentier, D., Manhaeghe, D., Baccini, L., Van Meirhaeghe, R., Rousseau, D.P.L., Van Hulle, S., 2020. A new reactor design for harvesting algae through electrocoagulation-flotation in a continuous mode. Algal Res. 47, 101828. https://doi.org/10.1016/j.algal.2020.101828

Sauchelli Toran, M., D’Haese, A., Rodríguez-Roda, I., Gernjak, W., 2020. Fouling propensity of novel TFC membranes with different osmotic and hydraulic pressure driving forces. Water Res. 175, 115657. https://doi.org/10.1016/j.watres.2020.115657

Vourch, M., Balannec, B., Chaufer, B., Dorange, G., 2008. Treatment of dairy industry wastewater by reverse osmosis for water reuse. Desalination 219, 190–202. https://doi.org/10.1016/J.DESAL.2007.05.013

FERTILIZATION AND UPTAKE OF MACROELEMENTS WITH MAIZE BIOMASS (A POT EXPERIMENT WITH PELIC VERTISOL)

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Keywords: fertilization rates, nitrogen, phosphorus, potassium and silicon fertilizers, N, P, K, Si uptake by dry matter of maize biomass.

ABSTRACT

The study aim is to evaluate the effect of different norms and combinations of nitrogen, phosphorus, potassium and silicon fertilizers in the soil type – Pelic Vertisol and their impact on the content and uptake of some main macro elements with medium-early hybrid Sunflower (*Zea maize L.*) – medium early hybrid P 8834, group 310 according to FAO. The experiment includes 16 variants of fertilization with 3 repetitions. Data are obtained on the yield of fresh and absolutely dry biomass from the above-ground part and the content of N, P, K and Si, in the resulting dry biomass from plants. According to the experimental data obtained, the content and uptake of the examined macro elements with maize biomass are significantly influenced by the imported norms and combinations of fertilizers. The highest is the uptake of nitrogen in the variants with the following norms: N_{200} and N_{300}. N uptake in variant with the highest norm (N_{400}) is a little bit smaller.
On the Leached smolnitza the export of K with corn was higher compared to the exports of all other elements examined. It was established that the changes in the macroelements uptake significantly follow changes in the quantities of the relevant elements in dry biomass in the variants of the experiment. With increasing rates of K fertilization, not only the content, but also its export with corn increases. For the rest of the elements N, P and Si, exports increase with the increase in the fertilization rate up to the N_{300}, P_{240} and Si_{1200} rates. At the same time, at the highest rates, respectively N_{400}, P_{320} and Si_{2000}, their exports with plants slightly decrease.

Materials and methods
In the spring of 2020 (22.05.), a pot fertilizer experiment with an early to mid-early hybrid of Maize (*Zea mays* L) - P 8834 of pioneer's FAO Group 310 was performed. The initial soil is Alluvial-meadow soil supplied by the experimental field in Bogurishte, Sofia region. According to the classification of soils in Bulgaria (Koinov, 1987), it is defined as Leached smolnitza, and Pelic Vertisol (FAO, 2015). It is characterized by a slightly acid reaction in the plowing horizon (pH_{H2O} - 6,4, pH_{KCl}-5.6), with high content of total (0,217%) and mineral N (40,32 mg N/kg soil). The soil has a low supply of mobile phosphorus (,92 мg P_2O_5 /100 g soil) and bigger quantity of available potassium (30,86 mg K_2O /100 g soil). The total quantity of SiO_2 is 73.56% (in % of ignition residue). Silicon in the form of SiO_2 has a significant share in the total chemical composition of the different soil types in Bulgaria (Raikov and Ganev, 1972; Garbouchev, 1974). The content of soluble Si is about 160 mg/100g soil and the quantity of exchangeable Si is 680 mg/100g soil, determined by extraction with 0,01M $CaCl_2$ and 0,5M CH_3COOH solutions, respectively (Berthelsen and Korndörfer, 2005). So, the studied soil is well stocked with Si.
Before sowing the seeds, fertilizers with different amounts of active substances in mg/pot were added to the experimental containers of 3 kg capacity, as presented in Table 1. Seven seeds were sown, leaving 4 plants in each pot at a later stage (16.06.). On the 67^{th} day of vegetation in the phase “8-9 leaves”, the plants were harvested, weighed, and prepared for chemical analysis. The content (%) of absolutely dry weight (a.d.w.) of macronutrients N, P, K and Si in maize plant biomass was determined by acid digestion and ICP readings (5800 ICP - OES system - Agilent). The export of the tested elements with the plant production was determined.
The experiment included 16 fertilization treatments in 3 replications. It is a multifactorial scheme with four factors varied at 5 levels (Sadovski, 2020). Table 1 shows the experimental design and the imported

amounts of the active substance of the macroelements used in mg/pot. There were used solid granular ammonium nitrate as a source of N, triple super phosphate – as P and solid potassium sulphate – as K macronutrient.

Conclusion

As a result of the vegetation fertilizer experiment on Leached smolnitza and the one-factor dispersion analysis of the values for the amount of biomass of plants on the 67th day, the leading role of fertilization with nitrogen high rates of 200, 300 and 400 mg/pot and silicon 800 mg/pot was established (the proven difference between the options is at a high level of confidence $P \leq 0.001$).

Nitrogen exports with the biomass is the highest in the N200 and N300 variants, andlowerin N400 variants. The export of K with maize is higher compared to the exports of all the other elements studied.

It has been found that the changes in exports of the macronutrients studied to a significant extent follow the changes in the quantities of the elements concerned in the dry biomass according to the trial variants. With an increase in the rates of fertilization with K, not only the content increases, but also its export with corn. In the other elements N, P and Si exports increase with increasing fertilization rate to N300, P240 and Si1200. At the same time, at the highest norms, respectively N400, P320 and Si2000, their exports with plants decreased slightly.

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References:

Arinushkina (1962). Guide to chemical analysis of soils. Moscow State *University Press. Moscow*. 490 p.

Berthelsen, S., Korndörfer G.H. (2005) Methods for silicon analysis in soil, plant and fertilizers. In: Proceedings of the Third International Conference on Silicon in Agriculture, Brazil, 85-91.

Bremner, J.M. (1965a). Inorganic Forms of Nitrogen. In: C.A. Black et al., /Eds./. *Methods of Soil Analyses. Part 2: Chemical and Microbiological Properties. № 9, Agronomy. American Society of Agronomy Inc. Madison, Wisconsin, USA,* pp. 1179-1237.

Bremner, J.M. (1965b). Organic Nitrogen in Soils, *Agron. 10*, 93-149.

Colomb, B., P. Debaeke, C. Jouany, J.M. Nolot, (2007). Phosphorus management in low input stockless cropping systems: Crop and soil responses to contrasting P regimes in a 36-year experiment in southern France, European Journal of Agronomy, Volume 26, Issue 2, 2007, Pages 154-165, ISSN 1161-0301, https://doi.org/10.1016/j.eja.2006.09.004.

https://www.sciencedirect.com/science/article/pii/S1161030106001262

Coskun, D., Deshmukh, R., Sonah, H., Menzies, J. G., Reynolds, O., Ma, J. F., et al. (2019). The controversies of silicon’s role in plant biology. *New Phytol.* 221.

Detmann, K. C., Araujo, W. L., Martins, S. C., Sanglard, L. M., Reis, J. V., Detmann, E., et al. (2012). Silicon nutrition increases grain yield, which, in turn, exerts a feed-forward stimulation of photosynthetic rates via enhanced mesophyll conductance and alters primary metabolism in rice. *New Phytol. 196,* 752–762.

Epstein, E., & Bloom, A. J. (2008). Mineral Nutrition of Plants: Principles and Perspectives, *2nd Edn. Sunderland: Sinauer Associations. 67–85*. doi: 10.1111/nph.15343.

Effects of mixed seeding of several plants with different growth forms on mitigating sand drifting in desertified grassland in the Northeast Asia

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Keywords : plant facilitation, mixed seeding, sand fixation, dust and sand storm (DSS)

ABSTRACT

Plant facilitation, defined as positive plant-plant interaction, strongly influences diversity, structure, and dynamics in plant communities through ameliorating micro-meteorological conditions and improving the soil physiochemical properties (Brooker and Callaghan, 1998; Callaway, 2007). In arid regions, the processes of plant facilitation are also affected by the physical conditions such as windbreak fences and other erosion control facilities (Qiu et al., 2004). Considerable attention has been paid to the countermeasures which could achieve the most effective environmental restoration by using plant facilitation as a tool to accelerate vegetation succession (Koyama et al., 2015a; Koyama et al., 2015b; Kimura et al., 2022). Findings of such studies can provide guidance for ecological restoration measures such as tree/shrub planting methods which would highly benefit plant facilitation (Suding et al., 2004; Suding and Hobbs, 2009; Sasaki et al., 2018; Kono and Okuro, 2021). However, a problem for applying plant facilitation to restoration is its context dependency. Thus, it is necessary to determine the conditions that maximize facilitation effects of target plants.

In arid and semi-arid regions of the Northeast Asia, the recent inappropriate land use such as over grazing and over cultivation has caused serious degradation of grasslands. Especially in sandy lands, extensive fields of sand dunes which are bio-climatically covered with vegetation, excessive human activities have enhanced climatic variables including wind and water, which caused irreversible degradation processes such as sand dune remobilization and dust and sand storm (Qiu et al., 2004; Li et al., 2009; Abulaiti et al., 2014). In Hulunbeier grassland, located in the Northeast China, restoration measures by planting/ seeding, straw checkerboard barrier (SC), and fencing have been implemented at shifting sand dune area. Among them, we focused on mixed seeding, seeding of perennial grass (*Elymus* spp.) and leguminous shrub (*Caragana microphylla*), as a unique method to facilitate the restoration of native grassland with high potentials of dust and sandstorm (DSS) mitigation and ecosystem services.

We assessed the effects of mixed seeding on DSS mitigation and land restoration by answering the following questions: (1) How is the restoration pattern at mixed seeding site different from those at other sites? (2) How do the grass and shrub interact in terms of plant facilitation? (3) Could mixed seeding contribute to mitigating wind erosion?

We selected Wangong village and surrounding area in Hulunbeier City, as the study area. We situated permanent monitoring plots with different treatments as follows; (a) mixed seeding applied in 2013 with SC and fence, (b) mixed seeding applied in 2014 with SC and fence, (c) SC and fence established in 2014 without mixed seeding, and (d) fence established in 2014 without mixed seeding as a control. We have continued the field surveys including vegetation and erosion/sedimentation at those plots for 5 years since 2014.

We also conducted simultaneous measurement of sand drifting to analyze the relation between vegetation restoration and sand drifting more precisely and to estimate threshold of wind speed at certain vegetation conditions which causes sand drifting. We selected 13 sand dunes including dunes with monitoring sites, as study area, and established 30 sites in total. At each site, we measured vegetation,

sand drifting by portable particle counters, and wind speed/direction by portable weather meters simultaneously from the last part of July to the first part of August in 2018 and 2019.

The results suggested that the mixed seeding was very effective in the promotion of vegetation restoration in terms of both quality (species richness and composition) and quantity (vegetation cover) in the early stages of succession, through facilitation of two sown species. The effectiveness of vegetation on the mitigation of wind erosion and sedimentation differed depending on dominant types. The results also suggested that mixed seeding could reduce sand drifting and contribute to the mitigation of wind erosion and sedimentation by covering ground surface quickly in the early stage of succession.

We also report the results of other ongoing field experiments conducted in Mongolia on mixed seeding with annual and perennial grass species.

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References:

Abulaiti, A., Kimura, R., Shinoda, M., Kurosaki, Y., Mikami, M., Ishizuka, M., Yamada, Y., Nishihara, E., Gantsetseg, B., 2014. An observational study of saltation and dust emission in a hotspot of Mongolia. Aeolian Research 15, 169-176.

Brooker, R.W., Callaghan, T.V., 1998. The balance between positive and negative plant interactions and its relationship to environ- mental gradients: a model. Oikos 81, 196–207.

Callaway, R.M., 2007. Positive interactions and interdependence in plant communities. Springer, Dordrecht, The Netherlands.

Kimura, K., Kono, A., Yamada, S., Koyanagi, T.F., Okuro, T., 2022. Grazing and heat stress protection of native grass by a sand-fixing shrub in the arid lands of northern China. Journal of Arid Land 14, 867-876.

Kono, A., Okuro, T., 2021. Spatial distribution of shrubs impacts relationships among saltation, roughness, and vegetation structure in an East Asian rangeland. Land 10, 1224.

Koyama, A., Sasaki, T.m, Jamsran, U., Okuro, T., 2015a. Shrub cover regulates population dynamics of herbaceous plants at individual-shrub scale on the Mongolian steppe. Journal of Vegetation Science 26, 441-451.

Koyama, A., Yoshihara, Y., Jamsran, U., Okuro, T., 2015b. Role of tussock morphology in providing protection from grazing for neighbouring palatable plants in a semi-arid Mongolian rangeland. Plant Ecology & Diversity 8, 163–171.

Li, Y., Cui, J., Zhang, T., Okuro, T., Drake, S., 2009. Effectiveness of sand-fixing measures on desert land restoration in Kerqin Sandy Land, northern China. Ecological Engineering 35, 118-127.

Qiu, G.Y., Lee, I.B., Shimizu, H., Gao, Y., Ding, G., 2004. Principles of sand dune fixation with straw checkerboard technology and its effects on the environment. Journal of Arid Environments 56, 449-464.

Sasaki, T., Koyama, A., Okuro, T., 2018. Coupling structural and functional thresholds for vegetation changes on a Mongolian shrubland. Ecological Indicators 93, 1264-1275.

Suding, K.N., Gross, K.L., Houseman, G.R., 2004. Alternative states and positive feedbacks in restoration ecology. Trends in Ecology and Evolution 19, 46-53.

Suding, K.N., Hobbs, R.J., 2009. Threshold models in restoration and conservation: a developing framework. Trends in Ecology and Evolution, 24, 271-279.

Green electricity: a renewable resources biotechnology and ecological engineering tool

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Keywords: bioelectricity; green roofs; photosynthesis-assisted energy generation; renewable energy.

ABSTRACT

The active exploitation of fossil non-renewable energy sources has led to critical environmental deterioration, pollution of human habitas and global climate change. Many countries and regions around the world are facing continuously rising surface temperatures and drought limiting their freshwater resources (Stefanakis, 2020). In this regard, the attention to alternative energy sources, the need for the development of environmentally safe technologies for obtaining electricity and the transition to carbon neutrality are indisputable. Green electricity obtained from the interaction of soil, living plants and rhyzospheral microorganisms meets all these requirements and is an intriguing renewable energy source.

Plant-microbial bioelectricity based on sustainable photosynthesis assisted power generation exploits the light-harvesting systems of phototrophic organisms (Rusyn, 2021). Higher plants may effectively capture and transform solar energy, resulting in synthesis of organics and exudation of root photosynthetants and metabolites and, oxygens, ensuring growth and development of rhyzospheral microorganisms (Strik et al., 2008). The conversion of organic material into electricity using microorganisms are emerging renewable energy generation systems (Paucar and Sato, 2021). The integration of these efficient energy generation systems with photosynthetic biological systems opens up new possibilities in the sustainable renewable energy industries.

Biotechnology of plant-microbial fuel cells (PMFC) is absolutely not harmful to the environment, because it uses natural or urbogenic ecosystems and the only intervention in the environment is the installation of electrodes in the soil and the collection of bioelectricity of living plants and microorganisms. An important advantage of this technology is exploitation and expansion of green spaces that promotes of carbon sequestration. This technology is available wherever there is vegetation and does not require large costs, and is essentially a renewable source of energy exploiting the power of sunlight, plants and microorganisms.

Plant-microbial biosystems for the generation of bioelectricity can be installed both in natural ecosystems, on green roofs of buildings or indoors. Installation of plant-microbial systems for energy generation on green roofs provides additional environmental benefits such as climate regulation and water management in settlements, energy saving with reduction of air conditioning and heating costs, as well as air purification, carbon sequestration and maintenance of plant, bird and pollinator biodiversity, etc (Liu et al., 2021).

Our studies have shown that biosystems based on *C. hirta* plants and bryophytes could serve as energy sources on building roofs. Power output of bryophyte and sedge based PMFC on green roof decreased during droughts and frosts, but fully recovered during optimal temperature and humidity conditions. Mosses are known as weeds on roofs around the world and grow in severe environmental conditions such arctic regions and deserts. Due to their resistance to drought and ultraviolet solar radiation, plus high and low temperatures, they can ensure the activity of electricity generation systems on roofs. Sedges based PMFC, which are resistant to low temperatures and arid conditions, were found to be even more tolerant to weathering compared to systems with mosses. Limiting factors for the operation of biosystems based on *C. hirta* are temperatures below 0°C, while for mosses it was 5°C. In pilot study, a succesful experiment where bioelectricity generation systems are operated for nine months in the continental climate zone of

Ukraine opens the prospects using sedges and mosses based biosystems after optimization to prevent energy loss during cold and drought periods.

Although, the theoretically calculated maximum power of biotechnology plant microbial electricity (Strik et al., 2011) for full scale use has not yet to be achieved, plant-microbial biosystems are nevertheless currently being developed to power low-energy devices (Gomora-Hernández et al., 2020, Apollon et al., 2021, Jawre et al., 2021). The bioelectricity generated biosystems in our research served as an autonomous and environmentally friendly energy source for a room weather station and LEDs, replacing 1.5 V and 3.0 V batteries in real-time. Limitations for large-scale use are caused by numerous insufficiently studied biological and technical factors and the environmental influences affecting its performance. Ensuring long-term stability and durability are crucial for their practical implementation.

The development of plant-microbial bioelectrical biotechnology promotes additional green acreage, including on building rooftops, as well as to the wider development of low-energy devices, which is another one of its advantages and a significant factor in the fight against the consequences of climate change and greenhouse gas emissions. Green bioelectricity biotechnology could be considered as 1) an important ecological engineering tool for carbon sequestration and air pollutions remediation, 2) a regulator of climate and water retention, and 3) guarantee of biodiversity while obtaining bioelectricity which would have a great potential in an upcoming circular society, living according to the principles of renewability and sustainabilty.

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References:

Apollon, W., Luna-Maldonado, A.I., Kamaraj, S.K., Vidales-Contreras, J.A., Rodríguez-Fuentes, H., Gómez-Leyva, J.F., Aranda-Ruiz, J., 2021, Progress and recent trends in photosynthetic assisted microbial fuel cells: A review, Biomass and Bioenergy 148, 106028, https://doi.org/10.1016/J.BIOMBIOE.2021.106028.

Gomora-Hernandez, J.C., Serment-Guerrero, J.H., Carreno-de-Leon, M.C., Flores-Alamo, N., 2020, Voltage production in a plant-microbial fuel cell using *Agapanthus africanus*, Rev Mex Ing Quim. 19(1), 227-237. https://doi.org/10.24275/rmiq/IA542.

Jawre A.K., Sandhu S.S, 2021, Production of green electricity from Cynodon dactylon in plant-bio-photovoltaic device, Int J Environ Sci Technol, 1-8, https://doi.org/10.1007/s13762-021-03518-5.

Liu, H., Kong, F., Yin, H., Middel, A., Zheng, X., Huang, J., *Xu, H., Wang, D.,* Wen, Z., 2021, Impacts of green roofs on water, temperature, and air quality: A bibliometric review, Building and Environment 196,107794, https://doi.org/10.1016/j.buildenv.2.

Paucar, N. E., & Sato, C., 2021, Microbial Fuel Cell for Energy Production, Nutrient Removal and Recovery from Wastewater: A Review, Processes 9, 1318. https://doi.org/10.3390/pr9081318.

Rusyn, I.B., 2021, Role of microbial community and plant species in perfomance of plant microbial fuel cells. Renewable and Sustainable Energy Reviews, 152, 111697, https://doi.org/10.1016/j.rser.2021.111697.

Strik, D.P.B.T.B., Hamelers, H.V.M., Snel, J.F.H., Buisman, C.J., 2008, Green electricity production with living plants and bacteria in a fuel cell, International Journal of Energy Research 32(9), 870–876. *https://doi.org/*10.1002/er.1397.

Strik, D. P. B. T. B., Timmers, R. A., Helder, M., Steinbusch, K. J., Hamelers, H. V., Buisman, C. J., 2011, Microbial solar cells: applying photosynthetic and electrochemically active organisms. Trends in Biotechnology, 29(1), 41-49. https://doi.org/10.1016/j.tibtech.2010.10.001.

Stefanakis, A.I., 2020, Constructed Wetlands for Sustainable Wastewater Treatment in Hot and Arid Climates: Opportunities, Challenges and Case Studies in the Middle East. Water 12 (6), 1665, https://doi.org/10.3390/w12061665.

Evaluating the impact of Nature-based Solutions on the provision of water-related and water-dependant Ecosystem Services

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Keywords: Water Management, Nature-based Solutions, Ecosystem Services, Monitoring Framework, IUCN Global Standard for NbS, Mediterranean.

ABSTRACT

Water is extremely scarce throughout the Mediterranean, a region that contains 3% of the world's water resources. Current patterns of water management have shifted from a supply-based to a demand-based approach, resulting in a seasonal mismatch between water sources and demands. As a result, natural water supplies are no longer sufficient to meet growing demands. Overuse of water resources for agriculture is one of the greatest threats to the water environment. It accounts for more than 70% of water withdrawals in the southern and eastern Mediterranean countries and is the main cause of pressure on natural waters, leading to the loss of aquatic ecosystems. This situation is aggravated by the increasing effects of climate change and seasonal variations, which affect freshwater resources in already water-scarce areas and can potentially develop into water stress conditions in new locations [0, 2]. To address this challenge, improvements in the management of the hydrologic cycle, including water harvesting, storage, and distribution, are needed in both natural and artificial water bodies, in addition to the introduction of wastewater treatment, reuse, and efficient water use.

Developing a nature-based approach to improve the efficiency of existing natural and grey water infrastructure can lead to a more sustainable and optimised response. Nature-based Solutions (NbS) are innovative approaches to restore degraded natural water ecosystems, maintain healthy ecosystems, and provide water-related and water-dependent Ecosystem Services [3]. In addition, NbS can be integrated into grey infrastructures to provide better services and improve their climate resilience and system performance [4]. Thus, the implementation of NbS has a direct impact on improving water availability, contributes to addressing water security and water governance challenges, and contributes to the Sustainable Development Goals (SDGs) and their targets [5]. However, the lack of a robust and impartial standardised assessment of current NbS measures in water management remains a challenge [6]. Therefore, a global approach is needed that (i) considers the positive impacts of localised NbS on the entire water cycle, including upstream and downstream impacts and interactions at the watershed level [7]; (ii) determines the right combination of NbS and grey infrastructure and their integration [8]; and (iii) employs user-friendly tools and methodologies that engage stakeholders to support decision-making and replication of NbS.

In this context, as part of the NATMed project (funded by the PRIMA programme), we have developed a monitoring framework to assess and evaluate the impact of NbS implementation. NATMed aims to improve water management in the Mediterranean region through the implementation of innovative NbS. Our combination of NbS represents a novel approach known as Full Water-Cycle - NbS, which can be applied to water infrastructures by providing Ecosystem Services throughout the hydrological process. The project's approach follows the eight criteria of the IUCN Global Standard and will stablish participatory and governance processes to incorporate local stakeholder perspectives and ensure replication and sustainability over time. The project will develop five case studies (CS) that address the optimization of

different types of water infrastructure and challenges: CS1 (Spain) focuses on improving the quantity and quality of treated water storage; CS2 (Greece) aims to improve the water quality and storage of a natural wetland and its distribution system; CS3 (Italy) aims to improve groundwater quality and storage with cost-effective and more efficient technological solutions; CS4 (Türkiye) addresses the challenges of groundwater storage capacity and distribution system efficiency; and finally, CS5 (Algeria) aims to improve the storage and efficiency of artificial distribution systems to reduce pollution and environmental degradation. The five case studies selected for our project exemplify the great geographic, economic, and social diversity of the Mediterranean region. In addition, our monitoring framework is based on the four categories for classifying Ecosystem Services (supplying, regulating, supporting, and cultural) and their classification as water-related or water-dependent Ecosystem Services [9, 10]. To further measure the impact of the solutions, a link between Ecosystem Services and Key Performance Indicators was established through a particular theory of change [11].

In conclusion, we propose a novel approach to measure the impacts of NbS deployment and operation that is guided by the IUCN Global Standard for NbS by considering impacts on water quality and quantity of existing infrastructure, and also incorporating environmental, social, and economic considerations.

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References:

1. Revolve water, 2017. Water around the Mediterranean. https://revolve.media/product/water-around-the-mediterranean-2017/
2. UNESCO World Water Assessment Programme, 2021. UN World Water Development Report 2021: Valuing Water. DOI: 10.18356/9789214030140
3. UNEP et al. (2014). Green Infrastructure Guide for Water Management: Ecosystem-based management approaches for water-related infrastructure projects.
4. Browder, G., Ozment,S., Rehberger, I., Gartner, T., and Lange, G.M., 2019. Integrating Green and Gray: Creating Next Generation Infrastructure.
5. United Nations Environment Programme, UNEP-DHI Centre on Water and Environment, & International Union for Conservation of Nature 2018. Nature-Based Solutions for Water Management: A Primer.
6. WWAP (United Nations World Water Assessment Programme)/UN-Water 2018. The United Nations World Water Development Report 2018: Nature-Based Solutions for Water. Paris, UNESCO
7. Matthews, J., Matthews, N., Simmons, E., and Vigerstol, K., 2019. Wellspring: Source Water Resilience and Climate Adaptation. Arlington, VA: The Nature Conservancy.
8. Cooper, R., 2020. Nature-based solutions for water security. K4D Helpdesk Report 813. Brighton, UK: Institute of Development Studies.
9. Russi D., ten Brink P., Farmer A., Badura T., Coates D., Förster J., Kumar R. and Davidson N., 2013. The Economics of Ecosystems and Biodiversity for Water and Wetlands. IEEP, London and Brussels; Ramsar Secretariat, Gland.
10. https://digital.iucn.org/water/nature-based-solutions-for-water/
11. European Commission, Directorate-General for Research and Innovation, 2021. Evaluating the impact of nature-based solutions: a handbook for practitioners. Publications Office of the European Union. https://data.europa.eu/doi/10.2777/244577

Hybrid constructed wetlands for enhance quality of urban aquatic ecosystems

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Keywords: Hybrid constructed wetlands, urban lake, runoff water and aquatic ecosystems

ABSTRACT

The world is facing problems related to the management of water resources. This is mainly due to increasing population density and rapid urbanization. The waters generated in urban areas are the main sources of contamination to aquatic ecosystems. Furthermore, aquatic systems such as urban lakes are affected due to sources of pollution originating from human activities. In many cases being used as receivers of rainwater and wastewater. The impacts to which these lagoons are subjected have generated loss of water quality (eutrophication) and ecosystem services. Due to the above, it is that in recent years the need has arisen to seek, evaluate and implement technologies for water treatment, which have characteristics of efficiency, autonomy and are economically viable. Among the most attractive solutions are constructed wetlands (CWs), which are passive purification systems that have been proven to be effective in treating domestic and industrial water. These systems are assembled by shallow lagoons or channels (<1 m), planted with vegetation from humid zones and in which the decontamination processes are based on physical, biological, and chemical processes that can occur simultaneously or sequentially between the vegetation, soil, and microbial assemblages. Furthermore, it has been determined that HC are effective in removing Organic Matter (OM) (75-95%), suspended solids (≥90%), NT (76-80%), and fecal indicators (>99%). The objective of this project was: to evaluate the application and environmental feasibility of using constructed wetlands to treat runoff water from urban lakes. With emphasis on physicochemical and biological evaluation. To achieve this, two hybrid CWs consisting of a vertical subsurface flow CW, followed by a horizontal subsurface flow CW (VSSF-HSSF) were evaluated. VSSF with 0.8 m and HSSF with 0.50 m saturation of water. Each unit was planted with *Schoenoplectus californicus*. The VSSF presented dissolved oxygen concentrations on average of 1.2 mg/L and the HSSF systems of 0.8 mg/L. N content for *Schoenoplectus californicus* on VSSF and HSSF was 2.7 gN/m^2 and 0.7 gN/m^2, respectively. The removal efficiencies in VSSF and HSSF were above 98% and 74% for total suspended solids (TSS), 87 and 69% for COD, nitrogen as ammonium (NH_4^+-N) was 77 y 83%, respectively.

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References:

Dunne, E. J., Coveney, M. F., Marzolf, E. R., Hoge, V. R., Conrow, R., Naleway, R., Inglett, P. W. 2013. Nitrogen dynamics of a large-scale constructed wetland used to remove excess nitrogen from eutrophic lake water. Ecological engineering, 61, 224-234. https://doi.org/10.1016/j.ecoleng.2013.09.039

Contreras, J., López, D., Gómez, G., Vidal, G. 2022. Seasonal enhancement of nitrogen removal on domestic wastewater treatment performance by partially saturated and saturated hybrid constructed wetland. Water, 14(7), 1089. https://doi.org/10.3390/w14071089

Vymazal, J., Kröpfelová, L. 2015. Multistage hybrid constructed wetland for enhanced removal of nitrogen. Ecological Engineering, 84, 202-208. https://doi.org/10.1016/j.ecoleng.2015.09.017

Enhanced Bioremediation of Polycyclic Aromatic Hydrocarbons by Laccases from two indigenous Fungal isolates via the ABTS Mediator Systems

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Keywords: Bioremediation, Fungi, Groundwater pollution, Polycyclic aromatic hydrocarbons, Laccase, , 2,2-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid

ABSTRACT

Many polycyclic aromatic hydrocarbons (PAHs) have been reported to be carcinogenic, mutagenic and teratogenic, although their effect on human health is largely dependent on the duration and route of exposure, as well as concentration and relative toxicity one is exposed to. The persistence, toxicity and widespread distribution of PAHs in the environment present a serious global concern, particularly regarding groundwater contamination. This study investigates the efficacy of purified laccases from *Trichoderma lixii* (*Tl*FLU-1) and *Talaromyces pinophilus* (*Tp*FLU-12) in oxidizing and detoxifying PAHs in a sole-substrate system, using 2,2-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) as a mediator. Integrating ecological elements and ecosystems underscores the sustainable approach adopted for groundwater remediation. The degradation of anthracene and fluoranthene was quantified using UV-Vis spectroscopy, while the metabolites were identified via gas chromatography-mass spectrometry (GC-MS). In the absence of a mediator, the free laccase assay exhibits V_{max} values of 1.35 ± 0.02 mg/L/hrs and 1.29 ± 0.02 mg/L/hrs, with K_m values of 119.2 ± 0.02 mg/L and 170.8 ± 0.03 mg/L for *Tl*FLU-1 and *Tp*FLU-12, respectively, during fluoranthene degradation. Similarly, V_{max} values of 3.51 ± 0.06 mg/L/hrs and 3.44 ± 0.06 mg/L/hrs, with K_m values of 173.2 ± 0.06 mg/L and 73.3 ± 0.07 mg/L, were obtained for *Tl*FLU-1 and *Tp*FLU-12, respectively, during anthracene degradation. The laccase-mediator system significantly enhances PAH degradation compared to the free laccase system. GC-MS analysis reveals that fluoranthene degradation was initiated at the C_1– C_2 position of the compound ring through oxygenation and ring cleavage, forming 9-oxo-9H-fluorene-1-carboxylic acid. The compound then enters the β-Ketoadipate pathway via benzene-1,2,3-tricarboxylic acid. Anthracene degradation involves two pathways: one unique to the ABTS system, involving hydroxylation and carboxylation at the C_1 and C_2 positions, leading to 3-hydroxy-2-naphthoic acid formation; the second pathway aligns with the most common anthracene degradation pathways. Time course analysis of the toxicity of the degradation products demonstrates a progressive reduction in acute toxicity of marine bacteria and reduced cytotoxicity against hippocampal neuronal cells (HT-22 cells), indicating the production of less toxic metabolites. Furthermore, studies on the gene expression associated with Alzheimer's disease (AD) in HT-22 cell lines treated with fluoranthene degradation products suggests that accumulated metabolites of fluoranthene degradation may induce neuronal damage and exhibit Alzheimer's – like pathological characteristics. Thus, this study highlights the potential of laccase-mediator systems as a promising, effective and sustainable avenue for addressing contamination challenges in an environmentally friendly manner.

Modelling Policy Options for GHG Mitigation in Polish Agriculture

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Keywords: agriculture, climate mitigation, food security, modelling, carbon pricing, subsidies, Poland

ABSTRACT

Understanding of sustainability is evolving and becoming more complex (Hajian and Kashani, 2021) through intensifying inclusion of interrelations with various economic, social, environmental and institutional phenomena. As complex sustainability challenges may never be fully solved, instead requiring continuous, adaptive, and reflexive engagement over time (McCrory et al., 2021), achievement of set policy goals at a particular timeframe requires seeking for optimisation between efforts and results based on an optimal set of trade-offs. Up until the year 2022, the environmental focus of the European Union's policies for future development prevailed, with the European Green Deal (EC 2019; EC 2020) and the "Fit for 55" package (EU 2021) stressing to intensify the efforts to reach climate neutrality by 2050.

Agriculture, especially in Poland, is a sector of economy characterised by low level of concentration and is being systematically supported within the EU's Common Agricultural Policy. Agriculture also performs crucial economic and social functions, both as a provider of food and employment for hundreds of thousands of inhabitants in rural areas. For this reason, instruments leading to the achievement of the emission reduction target should be carefully selected. To tackle this and other climate change issues, a long-term strategy for the sustainable development of agriculture in Poland (Zegar, 2021) is needed, especially in terms of the EU's climate action targets by such far horizon as 2050.

Modelling toolbox

The assessment has been conducted within the LIFE Climate CAKE PL and LIFE VIIEW 2050 projects during 2017-2022 utilising a set of interconnected modelling tools: the core d-PLACE model (Boratyński et al., 2022) – a global computable general equilibrium (CGE), as well as three sectoral models: MEESA for energy (Tatarewicz et al., 2022), TR^{3}E for transport (Rabiega et al., 2022), and EPICA for agriculture (Wąs et al., 2022).

The EPICA (Evaluation of Policy Impacts – Climate and Agriculture) model utilises several approaches to modelling. It combines linear farm activity optimisation programming with partial equilibrium, which allows for achieving an adequate supply–demand balance while making it possible to highly disaggregate analysed farm production activities. The EPICA model is currently focused solely on Poland and its agricultural sector. The GHG estimations are based on the IPCC (2006) guidelines.

Two key climate mitigation scenarios are being modelled within the presented research, both aiming to achieve climate neutrality by 2050. These two scenarios include the **NEU** (reflecting the implementation of the GHG reduction target for agriculture established as a result of the iterative procedure of the sectoral models and the d-PLACE model, using a set of currently used production activities and techniques in accordance with the "Fit for 55" package) and the **NEU+** (additionally assuming application of three selected climate mitigation measures available for the agricultural sector: a) increasing the CO_2 sequestration through afforestation of agricultural land, b) reducing GHG emissions from organic soils through rewetting of peatlands, and c) development of biogas plants aimed to reduce GHG emissions from livestock manure management).

Policy options

The way climate policy is implemented significantly affects the economic, environmental and organisational aspects of farm operations. Depending on the adopted option, the achievement of the reduction target may differentially affect the economic outcome of farms, production levels and prices, and food security. Findings show the potential effects of achieving climate policy targets in the agricultural sector of Poland within the two alternative scenarios (NEU and NEU+), each through all of the four following alternative policy options: SUBSIDIES (SUBS), CARBON PRICE (CP), LIMIT (LIM), and MIXED (MIX).

Results

As the initial results (Pyrka et al. 2021) of climate mitigation and reaching climate neutrality by 2050 in Poland (NEU) have shown drastic decreases in agricultural output (especially in the livestock sector), a need for additional mitigation measures has been detected, which could lessen the burden of GHG emission reduction on farms and allowing to achieve mitigation targets not limiting the agricultural output itself. Thus, three additional mitigation measures have been tested within the NEU+ scenario: afforestation of agricultural land, rewetting of organic soils, and developing the utilisation of manure for energy generation purposes (Table 1).

Table 1. Economic impact of the analysed policy options for mitigation of GHG emission in Polish agricultural sector (2015=100%)

Policy options	Policy scenarios					
	NEU			NEU+		
	Farmer income	Budget transfers	Prices of agricultural products	Farmer income	Budget transfers	Prices of agricultural products
SUBS	629	701	202	81	162	141
CP	-123	94 (-168)*	201	41	78 (68)*	185
LIM	96	95	197	23	87	140
MIX	360	397	201	107	123	143

* After inclusion of payments for emission allowances. Source: own (CAKE/KOBiZE) results and elaboration.

Conclusions

Key conclusions arising from the tested policies show that production volumes will decline and food prices are expected to increase. Outcomes of the NEU and NEU+ scenarios show how important it is to seek for reserves in mitigation of climate change. Study results show that the decline in agricultural production is caused by farmer motivation to avoid carbon taxation. Yet, the depths of these changes will differ depending on the way of implementation, namely on the approach adopted within a particular policy option. The NEU+ scenario allows keeping higher production volumes compared to the NEU, with the least decline within the mixed policy approach (NEU+ MIX), which simultaneously utilises GHG emission limits and subsidies. In our opinion, to mitigate climate changes it is necessary to seek additional measures to allow the reduction of greenhouse gasses and carbon sequestration, thus easing the potential burden placed on consumers.

Acknowledgements

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References:

1. Boratyński J, Pyrka M, Tobiasz I, Witajewski-Baltvilks J, Jeszke R, Gąska J, Rabiega W (2022). The CGE model d-PLACE, ver. 2.0, Institute of Environmental Protection - National Research Institute / National Centre for Emissions Management (KOBiZE), Warsaw.
2. EC (2019). Communication from the Commission "The European Green Deal". European Commission, 11.12.2019 (COM(2019) 640 final).
3. EC (2020). Impact Assessment for "Stepping up Europe's 2030 climate ambition. Investing in a climate-neutral future for the benefit of our people". SWD(2020) 176 final. European Commission, Brussels, 17.9.2020.

4. EU (2021). Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law').
5. Hajian M, Kashani SJ (2021). Chapter 1. Evolution of the concept of sustainability. From Brundtland Report to sustainable development goals. [In:] Sustainable Resource Management: Modern Approaches and Contexts. Edited by: Hussain CM and Velasco-Muñoz JF, 1-24. https://doi.org/10.1016/B978-0-12-824342-8.00018-3.
6. IPCC (2006). Guidelines for National Greenhouse Gas Inventories. Volume 4. Agriculture, Forestry and Other Land Use.
7. McCrory G, Holmén J, Holmberg J, Adawi T (2021). Learning to frame complex sustainability challenges in place: explorations into a transdisciplinary "Challenge Lab" curriculum. Frontiers in Sustainability 2:1-11. https://doi.org/10.3389/frsus.2021.714193.
8. Pyrka M, Jeszke R, Boratyński J, Tatarewicz I, Witajewski-Baltvilks J, Rabiega W, Wąs A, Kobus P, Lewarski M, Skwierz S, Gorzałczyński A, Tobiasz I, Rosłaniec M, Cygler M, Sekuła M, Krupin V (2021). Poland net-zero 2050: The roadmap toward achievement of the EU climate policy goals in Poland by 2050 (summary). Institute of Environmental Protection - National Research Institute / National Centre for Emissions Management (KOBiZE), Warsaw. https://climatecake.ios.edu.pl/download/64.
9. Rabiega W, Sikora P, Gąska J, Gorzałczyński A (2022). The TR^{3}E Model, ver. 2.0. Institute of Environmental Protection - National Research Institute / National Centre for Emissions Management (KOBiZE), Warsaw.
10. Tatarewicz I, Lewarski M, Skwierz S (2022) The MEESA Model, ver. 2.0, Institute of Environmental Protection - National Research Institute / National Centre for Emissions Management (KOBiZE), Warsaw.
11. Wąs A, Witajewski-Baltvilks J, Krupin V, Kobus P (2022). The EPICA model, ver. 2.0, Institute of Environmental Protection - National Research Institute / National Centre for Emissions Management (KOBiZE), Warsaw.
12. Zegar JS (2021). Long-term strategy for sustainable development of agriculture in Poland. Problems of Agricultural Economics 2:16-30. https://doi.org/10.30858/zer/138346.

Climate-neutral EU Regions: Expanding the mission of 100 EU carbon-neutral cities to 30 European carbon-neutral regions through S3 platform until 2030

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Keywords: climate change, mitigation, carbon-neutral cities, carbon-neutral regions, renewables, nature-based solutions

ABSTRACT

In line with the objectives of two key EU missions – 100 Climate-neutral and Smart Cities by 2030 and Adaptation to Climate Change, this study proposes an extension and enhancement of the mission aimed at achieving 100 European carbon-neutral cities. Our goal is to expand this mission to encompass 30 European carbon-neutral regions by leveraging the successful strategies and practices developed in the carbon-neutral cities initiative.

By undertaking this ambitious endeavour, we aim to establish a comprehensive framework for a bottom-up, participatory policy at the regional level across the European landscape. This framework will serve as a guide to help regions achieve carbon neutrality within the specified timeframe. It will consider the unique climate conditions of each region, as well as the potential of renewable energy sources and nature-based solutions (NBS) that can be harnessed to achieve carbon neutrality (Figure 1).

To ensure the effectiveness and accuracy of the transition process, we propose the integration of emission monitoring through already existing platforms as the S3 (smart specialisation strategy) or similars. This will allow for real-time verification of the progress made in transitioning towards carbon neutrality. By utilizing the platform, we can track and measure the impact of various initiatives and interventions implemented by the participating regions, facilitating a transparent and data-driven approach to climate action.

In conclusion, the expansion of the carbon-neutral cities mission to encompass carbon-neutral regions presents a crucial step towards achieving the EU's climate objectives and align our efforts with the broader EU climate agenda. This collaborative approach will foster knowledge exchange and replication of successful strategies across different regions, accelerating the overall progress towards a climate-neutral Europe. By combining regional climate conditions, renewable energy potentials, and NBS, our framework offers a practical and scalable approach to carbon neutrality. Using the S3 platform for emission monitoring, we can ensure accountability and transparency throughout the transition process. By linking our efforts to the existing EU missions, we can further strengthen the collective impact of our actions and drive Europe closer to a sustainable, climate-neutral future.

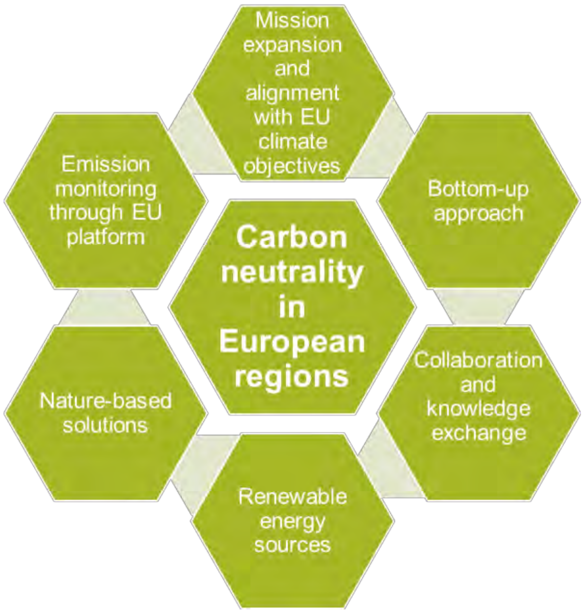

Figure 32. Framework for achieving carbon neutrality in European regions.

References

European Commission. 2022. EU Mission: Climate-Neutral and Smart Cities. https://ec.europa.eu/commission/presscorner/detail/en/IP_22_2591.

European Commission. 2022. EU Mission: Adaptation to Climate Change. https://climate-adapt.eea.europa.eu/en/mission.

Foray, D. Smart specialization strategies as a case of mission-oriented policy—a case study on the emergence of new policy practices. Industrial and Corporate Change, 2018, Vol. 27, No. 5, 817–832. doi: 10.1093/icc/dty030.

Scaling-up Nature-Based Solutions for decentralized greywater treatment retrofitted in urban areas of Costa Rica.

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Keywords: Nature-based Solutions, Decentralized greywater treatment, Spatial analysis, Latin America, On-site treatment.

ABSTRACT

In Costa Rica, 93% of the population has access to potable water, but only 14% of the served population has a sewerage service with a treatment system. The lack of conventional sanitation infrastructures has led to the implementation of domestic septic tanks for blackwater disposal and the discharge of untreated greywater into rivers, polluting surface water resources, especially in the Greater Metropolitan Area (GAM), the largest urban agglomeration in Costa Rica. Retrofitting sewerage networks and centralized treatment plants represent high investments and technical challenges, therefore, the current sanitation scheme is likely to prevail in the medium-term.

Nature-based Solutions (NbS), such as constructed wetlands, provide great contribution to greywater treatment by physical removal of solids and biochemical treatment. They are well-known simple, low-cost, low maintenance systems that could efficiently be applied for on-site treatment, as a useful cost-effective alternative to centralized sewerage and treatment systems. The implementation of on-site treatment allows pollutant removal at the source, hence, reducing pollutant loads being discharged to rivers, ultimately contributing to improve the environmental quality of water resources.

In this study, we analyze the technical potential and feasibility to scale up subsurface flow constructed wetlands for decentralized treatment of domestic greywater. An urban watershed in the Greater Metropolitan Area of Costa Rica was stablished as a case study area to develop the research. Using GIS tools, the quantity of greywater being discharged to the river, given the current situation, is estimated for the whole catchment area. A spatial analysis of the watershed was carried out to identify potential areas for the implementation of this type of NbS for on-site greywater treatment. Based on this analysis, a scenario for the treatment of greywater before discharge to the river is created. Taking account of the suitable areas for the implementation of this NbS along the watershed, an estimation of pollutants' reduction by virtue of the treatment is calculated, based on removal efficiencies reported in literature. The results contribute to the discussion and understanding of the potentiality of NbS to improve the environmental quality of surface water resources, not only in Costa Rica, but also other areas in the region where similar sanitation schemes prevail.

References

Bower, K.M. Water supply and sanitation of Costa Rica. Environ Earth Sci 71, 107–123 (2014). https://doi.org/10.1007/s12665-013-2416-x

Darner A. Mora Carlos F. Portuguez, Agua para consumo humano y saneamiento en Costa Rica al 2020: brechas en tiempos de pandemia. Instituto Costarricense De Acueductos Y Alcantarillados, 2021. San José, Costa Rica.

Fluhrer T, Chapa F, Hack J. A Methodology for Assessing the Implementation Potential for Retrofitted and Multifunctional Urban Green Infrastructure in Public Areas of the Global South. *Sustainability*. 2021; 13(1):384. https://doi.org/10.3390/su13010384

Boano F, Caruso A, Costamagna E, Ridolfi L, Fiore S, Demichelis F, Galvão A, Pisoeiro J, Rizzo A, Masi F, A review of Nature-based Solutions for greywater treatment: Applications, hydraulic design, and environmental benefits, Science of The Total Environment, Volume 711, 2020, 134731, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2019.134731.

Hack J, Schröter B. Nature-Based Solutions for River Restoration in Metropolitan Areas. in The Palgrave Encyclopedia of Urban and Regional Futures. 2021 doi: 10.1007/978-3-030-51812-7_166-1

Khajvand, M., Mostafazadeh, A.K., Drogui, P. *et al.* Greywater characteristics, impacts, treatment, and reclamation using adsorption processes towards the circular economy. *Environ Sci Pollut Res* 29, 10966–11003 (2022). https://doi.org/10.1007/s11356-021-16480-z

Masoud, A.M.N.; Alfarra, A.; Sorlini, S. Constructed Wetlands as a Solution for Sustainable Sanitation: A Comprehensive Review on Integrating Climate Change Resilience and Circular Economy. Water 2022, 14, 3232. https:// doi.org/10.3390/w14203232

Arthur N, Hack J. A multiple scale, function, and type approach to determine and improve Green Infrastructure of urban watersheds, Urban Forestry & Urban Greening, Volume 68, 2022, 127459, ISSN 1618-8667, https://doi.org/10.1016/j.ufug.2022.127459.

Pérez Rubi, M., Hack, J. Co-design of experimental nature-based solutions for decentralized dry-weather runoff treatment retrofitted in a densely urbanized area in Central America. Ambio 50, 1498–1513 (2021). https://doi.org/10.1007/s13280-020-01457-y

Pérez-Salazar R, Mora-Aparicio C, Alfaro-Chinchilla C, Sasa-Marín J, Scholz C, Rodríguez-Corrales J.A., Biogardens as constructed wetlands in tropical climate: A case study in the Central Pacific Coast of Costa Rica, Science of The Total Environment, Volume 658, 2019, Pages 1023-1028, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2018.12.259.

S. Arden, X. Ma. Constructed wetlands for greywater recycle and reuse: A review, Science of The Total Environment, Volume 630, 2018, Pages 587-599, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2018.02.218.

Neumann V, Hack J, Revealing and assessing the costs and benefits of Nature-based Solutions within a real-world laboratory in Costa Rica, Environmental Impact Assessment Review, Volume 93, 2022, 106737, ISSN 0195-9255, https://doi.org/10.1016/j.eiar.2022.106737.

A Bio-Refinery Concept for N and P Recovery—A Chance for Biogas Plant Development

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Keywords: biogas plant; struvite precipitation; ammonia stripping; circular bioeconomy; digestate treatment

ABSTRACT

Biogas is an eco-friendly energy alternative to fossil fuels. During the conversion of organic materials to biogas, a significant amount of digestate is produced. To ensure the sustainability of the entire process, it is important to utilize the digestate. This creates a challenge to the biogas industry, which is always seeking new technologies to process digestate and broaden its utilization. The digestate can be a substrate for the production of valuable mineral fertilizers. With phosphate rock reserves dwindling, it's important to consider constructing a bio-refinery that can recover nitrogen and phosphorus as struvite and ammonium sulfate from digestate. This eco-friendly approach could be a viable alternative to using commercial nitrogen-phosphorus.

The bio-refinery was situated at the Experimental Dairy Farm 'De Marke' in Hengelo (Gld), the Netherlands. Within the bio-refinery, cattle slurry (S) underwent anaerobic digestion (1), and the resulting biogas was utilized to generate energy (2). The CHP installation consisted of a gas engine (MAN E0824 E302) and generator, with an electrical capacity of 36 kWe and thermal capacity of 51 kWth. The produced heat was employed to maintain the temperature of the digestion process, while the electricity was utilized to cover the Experimental Dairy Farm De Marke's own consumption or sold over the public electricity grid. After the sanitation process (using pasteurization - keeping the material at 70°C for at least 60 minutes), the remaining digestate (DS) was divided into solid (SFDS) and liquid (LFDS) fractions. The LFDS was processed in three stages. First, struvite ($MgNH_4PO_4 \cdot 6H_2O$) (STR) precipitation was used to extract phosphorus and nitrogen from LFDS. Second, ammonium sulfate $(NH_4)_2SO_4$ (Bio-AS) was produced at 70°C in the ammonia stripping installation to increase N recovery efficiency. Third, the effluent (EFL) after ammonia stripping was directed to a duckweed pond, where duckweed (*Lemna minuta, LM*) was grown and served as fodder for cattle on the farm. The pond was designed to keep the duckweed until it absorbed nutrients to an acceptable level for dumping the pond water. A scheme of the bio-refinery system on the farm scale is shown in Figure 1 [1].

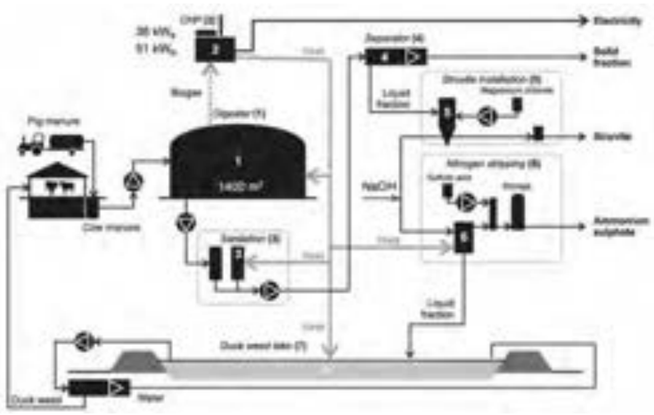

Figure 1. Scheme of the integrate the bio-refinery system on a farm scale. Source [1]

The content of N, P and Mg in STR was 23.1, 39.4, 32.3 g kg^{-1} respectively [2]. In the recovered product except pure struvite, the content of monohydroxycalcite ($CaCO_3 \cdot H_2O$) and quartz (SiO_2) was detected (Figure 2). The obtained Bio-AS was characterized by a low content of N_{tot} (14.1 g·kg^{-1} FM) and S_{tot} (16.8 g·kg^{-1} FM). The content of pure $(NH_4)_2SO_4$ was only 66.0 g·kg FM [1,3]. The P, and N recovery efficiency, calculated as the difference between the P_{tot} and N_{tot} content in the LFSD and the EFL, reached 43.8% and 43.2%, respectively. Low P recovery efficiency could be caused by the Ca, K in the LFSD (Table 1) as these elements are considered STR precipitation inhibitors.

Table 1. The physicochemical properties of organic materials flowing through the farm scale bio-refinery

	S	DS	SFDS	LFDS	EFL
pH	7.0^{a}	7.8^{b}	7.7^{b}	7.8^{b}	12.2^{c}
DM (%)	7.7 ± 0.1^{b}	6.8 ± 0.2^{b}	25.7 ± 1.1^{c}	3.3 ± 0.03^{a}	2.1 ± 0.1^{a}
N_{tot} (g·kg^{-1} FM)	3.6 ± 0.1^{c}	3.4 ± 0.01^{bc}	4.3 ± 0.2^{d}	3.2 ± 0.01^{b}	1.8 ± 0.1^{a}
NH_4-N (g·kg^{-1} FM)	2.9 ± 0.1^{b}	3.0 ± 0.1^{b}	3.0 ± 0.1^{b}	3.0 ± 0.03^{b}	1.4 ± 0.05^{a}
P_{tot} (g·kg^{-1} FM)	0.4 ± 0.01^{a}	0.4 ± 0.01^{a}	1.3 ± 0.1^{c}	0.3 ± 0.0^{ab}	0.2 ± 0.0^{b}
K_{tot} (g·kg^{-1} FM)	4,6 ± 0.1^{b}	4,7 ± 0.2^{b}	4,6 ± 0.1^{b}	3,8 ± 0.2^{a}	3,8 ± 0.2^{a}
Mg_{tot} (g·kg^{-1} FM)	0.7 ± 0.04^{cd}	0.6 ± 0.05^{bc}	0.9 ± 0.2^{d}	0.5 ± 0.01^{b}	0.3 ± 0.02^{a}
Ca_{tot} (g·kg^{-1} FM)	1.0 ± 0.1^{c}	0.9 ± 0.1^{bc}	1.6 ± 0.3^{d}	0.6 ± 0.06^{b}	0.4 ± 0.01^{a}

Data (means ± standard deviation, n = 3) followed by different letters in the same rows are significantly different at $P < 0.05$. S – slurry, DS – digested slurry, SFDS – solid fraction of digested slurry, LFDS – liquid fraction of digested slurry, EFL –effluent from biogas plant after struvite precipitation and ammonia stripping. FM – fresh matter. Source: [1]

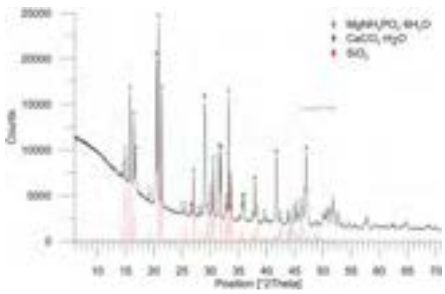

Figure 2. X-ray diffraction pattern of the product from the bio-refinery. Source: [1]

The results show that duckweed culture, in a growth medium with an EFL from the LFDG treated in a biorefinery, allowed for the effective recovery of minerals and the production of high-quality feedstuff for animals [4]. The N and P recovery reached approximately 75% and 45%, respectively. However, there was still a significant amount of sodium in the growth medium, after the duckweed harvest. Therefore, further research should be focused to find species of duckweed capable to absorb more sodium from the growth medium. Duckweed produced in the biorefinery proved to be a valuable high-protein feedstuff with a protein content of approximately 36% in dry matter.

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References:

1. Szymańska, M., Szara, E., Sosulski, T., Wąs, A., Van Pruissen, G.W.P., Cornelissen, R.L., Borowik, M., Konkol, M. 2019. A Bio-Refinery Concept for N and P Recovery—A Chance for Biogas Plant Development. Energies *12*, 155, https://doi.org/10.3390/en12010155
2. Szymańska, M., Szara, E., Wąs, A., Sosulski, T., van Pruissen, G.W.P., Cornelissen, R.L. 2019. Struvite—An Innovative Fertilizer from Anaerobic Digestate Produced in a Bio-Refinery. Energies 12, 296, https://doi.org/10.3390/en12020296
3. Szymańska, M., Sosulski, T., Szara, E., Wąs, A., Sulewski, P., van Pruissen, G.W.P., Cornelissen, R.L. 2019. Ammonium Sulphate from a Bio-Refinery System as a Fertilizer—Agronomic and Economic Effectiveness on the Farm Scale. Energies 12, 4721, https://doi.org/10.3390/en12244721
4. Sońta, M., Łozicki, A., Szymańska, M., Sosulski, T., Szara, E., Wąs, A., van Pruissen, G.W.P., Cornelissen, R.L. 2020. Duckweed from a Biorefinery System: Nutrient Recovery Efficiency and Forage Value. Energies 13(20), 5261, https://doi.org/10.3390/en13205261

Reduced tillage, fertilizer placement, and soil afforestation as methods of CO_2 soil emissions mitigation

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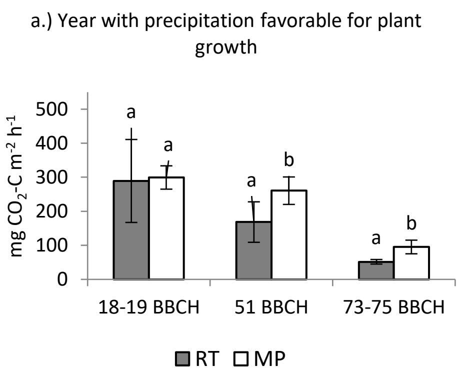
Keywords: soil CO_2 mitigation practices; arable land; forest soil

ABSTRACT

The European Green Deal has set a goal to reduce the EU's greenhouse gas (GHG) emissions by 50% by 2030. This requires implementing methods to reduce GHG emissions from agriculture, which is a major contributor to GHG emissions. A study was conducted to assess the impact of three mitigation practices: 1. reduced tillage, 2. deep placement of fertilizers, and 3. soil afforestation on CO_2 emissions from sandy soils in Central Poland. The findings from this study can aid in predicting the effectiveness of these methods. A short-term experiment was conducted at the Experimental Stations in Baborówko, located in western Poland (52°58′ N, 16°63′ E) to assess the impact of reduced tillage on CO_2-C emissions from soil (1). In a farm field experiment conducted in Kuklówka Zarzeczna, Central Poland, the impact of different fertilizer application methods, i.e. top dressing (TD) and deep placement at a depth of 10 cm (DP10) and 20 cm (DP20) on soil CO_2-C emissions was studied (2). The study on CO_2-C emissions from arable and forest soil (Scots pine stand) was carried out in Mikanów village (52°08′25″ N, 21°35′11″ E) in Central Poland (3). CO_2-C soil fluxes were measured in situ using a portable FT-IR spectrometer model Alpha (Bruker, Germany) equipped with the device chamber.

Under the moldboard plow (MP) system, the average soil CO_2-C flux ranged from 218.4 to 263.7 mg CO_2-C m^{-2} h^{-1}. Under a reduced tillage (RT) system, the range was from 169.7 to 163.6 mg CO_2-C m^{-2} h^{-1} in a year with precipitation favorable for plant growth and under drought conditions, respectively (Figure 1).



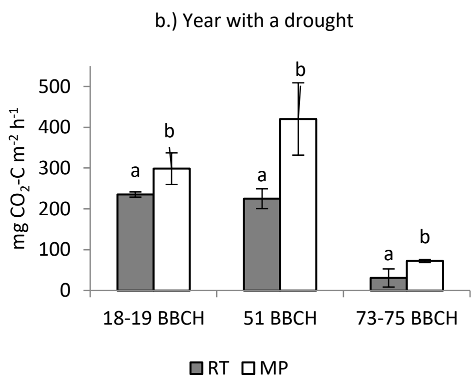


Figure 1. Soil CO_2-C fluxes in RT (reduce tillage) and MP (moldboard plow) cropping systems in an optimal moisture year (a) and a dry year (b) in a short-term experiment in Baborówko. Different letters (a, b) indicate significant differences ($p < 0.05$) among treatments (RT, and MP) (separately for test dates) (Source: Sosulski et al, 2022).

Similar amounts of CO_2-C were released from the soil that was fertilized to the soil surface (TD) and after mineral fertilizers were applied at depths of 10 cm and 20 cm (approximately 132.0 mg CO_2-C m^{-2} h^{-1}) (Figure 2). The forest soil emitted an average of 123.3 mg CO_2-C m^{-2} h^{-1} with fluctuations ranging from 3.44–405.47 mg CO_2-C m^{-2} h^{-1}, whereas CO_2-C fluxes from arable soil under maize reached 84.58 mg CO_2-C m^{-2} h^{-1} (3.63 to 302.31 mg CO_2-C m^{-2} h^{-1} during the growing period) (Figure 3).

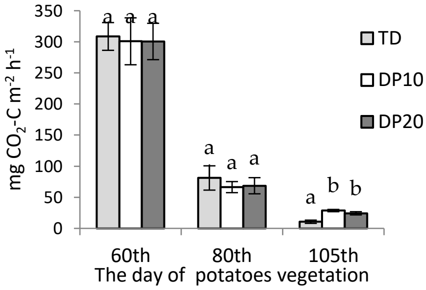


Figure 2. Soil CO_2-C fluxes under the influence of TD, DP10, and DP20 fertilization in a field experiment in Kuklówka Zarzeczna (Central Poland). Different letters (a, b) indicate significant differences ($P<0.05$) among treatments (TD, DP10, and DP20) (separately for test dates) (Source: Sosulski et al, 2022).

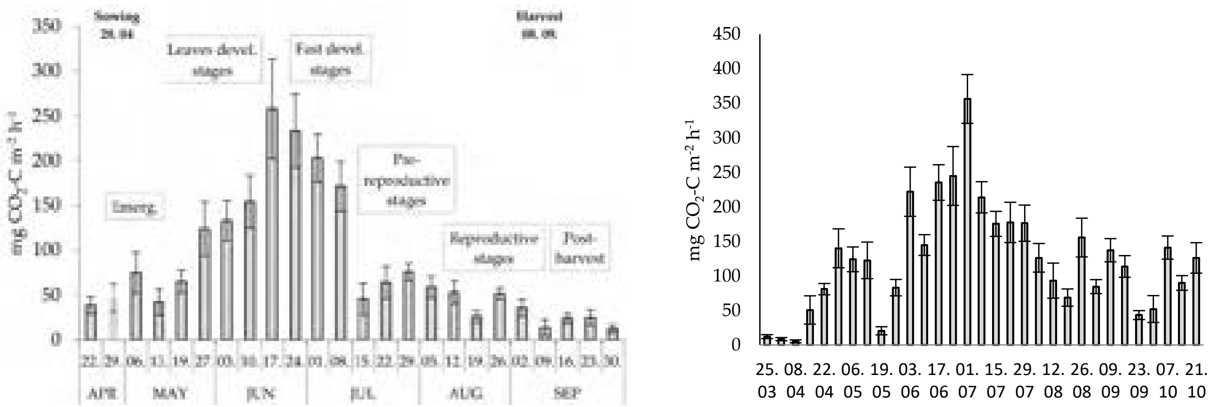


Figure 3. Soil CO_2-C fluxes from the arable soil (a) and forest soil under a pine stand (b) in Mikanów (Source: Sosulski et al, 2020; Sosulski et al, 2022)

The results showed that reduced tillage on sandy soil reduced CO_2-C emissions from the soil by 28.7-61.2% in normal and drought weather, respectively. Fertilizer deep placement did not reduce CO_2-C emissions from sandy soil. CO_2-C emissions from forest soils were even higher (by approximately 45.9%) than from arable soils. This means that the effectiveness of reducing CO_2-C emissions from the soil by afforestation of low-productivity sandy soils may rely more on the quantity of CO_2-C absorbed by the trees through photosynthesis than on soil respiration. Among the analyzed practices for mitigating CO_2-C emissions from sandy soils, the most effective is the reduced tillage plant cultivation system.

Acknowledgements
Special thanks to the Staff of the Experimental Station in Baborówko belongs to the Institute of Soil Science and Plant Cultivation State Research Institute in Pulawy, and the Klukówka Zarzeczna farm owner – for professional support for the conducted research.

References:

Sosulski, T., Niedziński, T., Jadczyszyn, T., Szymańska, M. 2022. Influence of Reduced Tillage, Fertilizer Placement, and Soil Afforestation on CO_2 Emission from Arable Sandy Soils. Agronomy, 12(12):3102, https://doi.org/10.3390/agronomy12123102

Sosulski, T., Szymańska, M., Szara, E. 2020 CO_2 Emissions from Soil Under Fodder Maize Cultivation. Agronomy, 10, 1087, https://doi.org/10.3390/agronomy10081087

Exploring the Hydrological Dynamics of Kifissos Basin in Greece: An Integrated Analysis of Water and Groundwater Resources

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Keywords: Kifissos Basin, Water resources, Groundwater dynamics, Hydrological modeling, Sustainability, Water management

ABSTRACT

Nowadays, the evaluation of the effectiveness of various preventive measures, including regulations, governance, and non-technological approaches (NBS technology), is crucial considering the reduction of chemicals release at their source. The UPWATER project, among other goals, seeks to develop and validate bio-based engineered natural treatment systems as mitigation solutions to safeguard groundwater (GW) from pollution. The performance of these bio-based measures will be assessed, and simulations will be conducted to determine their scalability and potential environmental benefits for wider adoption.

The project will focus on three case studies located in Denmark (DK), Greece (GR), and Spain (ES), representing different socio-economic contexts, hydrogeological conditions, and climates, each facing distinct GW pollution challenges. A participatory approach involving relevant local and regional stakeholders will be adopted to define and analyse the preventive measures. Notably, the Kifissos basin in Greece will serve as the case study for the project. Through comprehensive monitoring, modelling, and mitigation strategies, UPWATER aims to address GW pollution issues and provide valuable insights for sustainable water management practices.

The Kifissos Basin, located in Greece and discharged into Mediterranean Sea, is a region of vital importance for understanding the dynamics of water resources and groundwater systems in a highly urbanized and anthropogenically impacted environment. The Athens urban area extends over 412 Km^2 (Argyraki et al.) with a population of 3.8 million people. The metropolitan city has a typical Mediterranean climate with mild, moderately rainy winters and hot, dry and sunny summers. The average temperatures range between 10^{o}C in January to 29^{o}C in August, while annual precipitation is 513 mm per year.

The study employs an integrated approach, combining 1) hydrological modeling, 2) field investigations (sampling campaigns), and 3) data analysis to assess the current state of the Kifissos Basin's water resources. Key hydrological indicators, such as streamflow, groundwater levels, and water quality parameters (e.g NO^3, Ca), are evaluated to provide a holistic understanding of the basin's hydrological dynamics.

Firstly, a hydrological model will be developed to simulate the flow regime, water availability, and seasonal variations in the river as well as the groundwater of the basin. Additionally, several pollutants (organic and inorganic pollutants as well as pathogens) are taken into consideration, in order to pick point possible leakages at the sewage network of EYDAP. The model is going to calibrate and validate using historical data in addition to those that were excavated from the sampling campaign that was done by the NTUA. This enables the quantification of the water resources and the identification of factors influencing their variability. The results provide insights into the hydrological response of the basin to different climatic and land use scenarios as well.

Secondly, this study explores the groundwater system in the Kifissos Basin. Groundwater plays a crucial role in sustaining baseflow, supporting ecosystems, and meeting water demands during dry periods. A combination of geological formations (Koutsomitrou et al.), the monitoring well networks, and groundwater modelling (Koltsida et al.) is utilized to characterize the aquifer properties, assess the groundwater availability, and evaluate potential impacts from pumping and land use changes. The findings

will shed light on the groundwater-surface water interactions and highlight the vulnerability of the aquifer to anthropogenic pressures.

Furthermore, this research addresses the water quality challenges in the Kifissos Basin. The impacts of urbanization, industrial activities, and agricultural practices on water quality are analysed using water sampling and laboratory analysis (Goru R. C., Schimer et al.). The study will identifiy pollutant sources, evaluates their transport mechanisms, and assesses their effects on both surface water and groundwater quality. Recommendations for water quality management and pollution control measures will be proposed to mitigate the risks and protect the water resources of the basin.

Lastly, this study presents integrated water resources management strategies for sustainable water resource utilization in the Kifissos Basin, such as Nature-base Solutions (NBS). This project illuminates the importance of stakeholder engagement, policy interventions and the bio-base mitigation solution for the successful sustainability of the basin.

In conclusion, the UPWATER project will provide an integrated analysis of the water and groundwater resources in the Kifissos Basin, Greece. The findings of this research will contribute to the understanding of water management and the groundwater flow and quality (Panagiotopoulos et al.) in urbanized basins and provide valuable insights for water managers and researchers involved in water resources planning and decision-making.

Acknowledgements

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References:

Argyraki A., Paraskos F., Marmara M., Papadopoulou K., Maglaropoulou A., 2013. Comparative geochemistry of three urban streams in athens: Kifissos - Podoniftis – Pikrodafni, Xania, Greece

Gogu R. C., 2022. Urban Hydrogeology Studies, Switzerland

Koltsida E., Mamassis N., Kallioras A., 2023. Hydrological modeling using the Soil and Water Assessment Tool in urban and peri-urban environments: the case of Kifisos experimental subbasin (Athens, Greece), Hydrol. Earth Syst. Sci., 27, 917–931, 2023 https://doi.org/10.5194/hess-27-917-2023

Panagiotopoulos I., Kapsimalis V., Hatzianestis I., Kanellopoulos D. K., Kyriakidou C., 2009. Environmental status of the metropolitan river (Kifissos) of Athens, Greece, Environ Earth Sci (2010) 61:983–993 DOI 10.1007/s12665-009-0417-6

Schirmer M., Leschik S., Musolff A., 2012. Current research in urban hydrogeology – A review. Advances in Water Resources · July 2012 DOI: 10.1016/j.advwatres.2012.06.015

CIRAWA: Agroecological Solutions for Resilient Farming in West Africa: Identification of farmers' and communities' needs

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Keywords: Agroecology, West Africa, Resilient Farming, Key Informant Interviews, Co-creation, Indigenous-Scientific Knowledge.

ABSTRACT

Climate change is projected to compromise agricultural production, especially in smallholder systems with little adaptive capacity, as is currently prevalent in many parts of Africa. In particular, West Africa (WA) is known to be especially vulnerable to climate change, due to high climate variability or high reliance on rain-fed agriculture, and notably due to the urgent drive to meet food availability, healthy diet, and economic needs.

To support a transition to sustainable food systems, agroecological farming is emerging as a compelling response to the challenges West Africa faces, aiming to reduce the environmental impacts of agriculture while meeting the growing demand for food, contributing to landscape quality and biodiversity, and enhancing resilience.

With a view to achieving a just and sustainable food system, agroecology has established 10 elements to build on: diversity, synergies, efficiency, resilience, recycling and co-creation and knowledge sharing (describing the common characteristics of agroecological systems, basic practices and innovation criteria); human and social values and food culture and traditions (highlighting contextual aspects); circular and solidarity economy and responsible governance (addressing the enabling environment).[1] All these principles are reflected in actions such as the use of biofertilisers (compost), in the design of the production system (crop rotation, intercropping, agroforestry), tillage change actions (minimum tillage, direct sowing in cover crops or mulching), optimisation of irrigation systems (drip irrigation), etc.[2]

The CIRAWA project will unlock the potential of the agroecology in four countries of West Africa (Cape Verde, Ghana, Gambia and Senegal) by building on existing indigenous and scientific knowledge to improve food and nutrition security, livelihoods and planetary health while tackling the climate change and environmental impact of agricultural practices.

CIRAWA will work on innovative agro-ecological approaches with the following strategies:

- Valorisation of agricultural residues and production of organic fertilisers. Conducting a comprehensive inventory of all available resources by identifying the potential uses of these bio-products as fertilisers, as compost, as material for energy production or as building material.
- Selection of high-quality seeds for the main crops in West Africa. An inventory will be carried out of the different local seed varieties available and their characteristics will be evaluated in terms of ecological adaptation, yield, resistance to drought or rain, germination and growth time.... Protocols for seed production and replication will be defined.
- Phytoremediation and amendments for restoration and improvement of saline and polluted soils. Different crops and halophilic trees that have the capacity to grow in saline environments and reduce the concentration of salts in the soil will be used. In addition, microbial communities that influence plant growth in soils with high salt concentrations will be characterised.
- Management of agricultural practices to improve soil fertility. The different soils and nutritional deficiencies that impede the correct growth of plants will be studied and consequent action will be taken to improve soil fertility with agro-ecological techniques.

- Crop management. A platform will be developed to assist farmers in crop management by providing them with information on the different agroecological practices they can adopt depending on the situation of their crops/soils.

- Sustainable water use and management. A tool will be implemented to manage irrigation and fertilisation of fields, informing end users of the water and nutrient needs of crops on a continuous way.

In order to achieve all this, the involvement and participation of local communities/farmers and administrations is necessary to be able to accurately define the requirements and needs of each one of them, as well as to establish the baseline from which they start, not only at an agro-ecological level but also in terms of socio-economic and environmental aspects. The participation of local stakeholders is also indispensable to identify the potential of natural resources and ecosystem services in each area.

Focus groups, Key Informant Interviews and in-depth semi-structured questionnaires have been designed to collect socio-economic, environmental and gender data. The questionnaires have been designed for Household heads (HHH) and for Women in Household (WiHH) and divided into the following sections:

- DEMOGRAPHIC AND SOCIOECONOMIC CHARACTERISTICS OF HOUSEHOLDS
- CROP FARMING SYSTEMS
- OUTPUT AND INCOME FROM CROP FARMS (Last major season's harvest)
- FARMING SYSTEMS: LIVESTOCK
- IRRIGATION
- HHs OTHER SOURCES OF INCOME IN THE PAST ONE YEAR
- EXPENDITURE IN THE PAST ONE YEAR
- HOUSEHOLD FOOD AND NUTRITION SECURITY
- USE OF NATURAL RESOURCES
- GENERAL CHANGES IN LAND USE OVER TIME
- NATURAL RESOURCES DEGRADATION
- WEALTH (POVERTY) STATUS
- AGROECOLOGICAL/CLIMATE SMART/SUSTAINABLE LAND MANAGEMENT PRACTICES
- YIELDS CHANGE OVER TIME
- CLIMATE CHANGE
- ANTI-ENVIRONMENT PRACTICES
- RESOURCE USE-BASED CONFLICTS
- DIGITAL TOOLS

Agroecology does not offer fixed solutions, but must be adapted to the environmental, social, economic, cultural and political context in which it is implemented. For this reason, the development of a robust baseline is a key point for the correct selection of the solutions to be implemented.

The CIRAWA project is surveying at least 2,000 farmers in eight selected regions in the four countries where it will implement and monitor the agroecological solutions and will conduct a survey using analytical software such as Stata, SPSS and R (for quantitative) and NVivo and ATLAS.ti (for qualitative) that can give us specific and segregated information on each of the sections.

Acknowledgements

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References:

[1]. The 10 Elements of Agroecology: Guiding the transition to sustainable food and agricultural systems

[2]. Wezel, A., Casagrande, M., Celette, F. et al. Agroecological practices for sustainable agriculture. A review. Agron. Sustain. Dev. 34, 1–20 (2014). https://doi.org/10.1007/s13593-013-0180-7

Biohydrogen production from household food waste through dark fermentation: the possibility of water minimization during dilution

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Keywords: food waste, municipal wastewater, hydrogen, dark fermentation, dilution

ABSTRACT

Biohydrogen is a promising CO_2- neutral biofuel, which is nontoxic and may be derived from a wide variety of raw, renewable materials. Fermentative hydrogen production of food waste can contribute to both food waste minimization and energy recovery. However, the dilution of wastes/wastewaters used, with tap water, still remains a major environmental issue during dark fermentation.

In this study, long term continuous biohydrogen production from household food waste through dark fermentation, was investigated, exploring simultaneously the possibility of water minimization, during dilution. Specifically, two identical CSTR – type lab- scale bioreactors of 0.46 L working volume, described in Alexandropoulou et al. (2018), were operated at 35.5°C and fed with the liquid fraction after centrifugation of dried and shredded household food waste (FORBI). At the first one, FORBI was diluted with tap water (CSTR-1) and at the second one (CSTR-2), with municipal wastewater (MW), obtained from a local wastewater treatment plant. Both CSTRs operated for 72 days, during which four different HRTs were tested (24,12,8 and 4 h). The biogas produced consisted mainly of hydrogen and carbon dioxide and it was free of methane, indicating that there was not methanogenic activity in the reactor.

In figure 1, percentage of hydrogen in the gas phase, as well as hydrogen production rates in CSTR-1 and CSTR-2, are depicted while in tables 1 and 2 the main characteristics of both reactors at steady states, are also presented. It is obvious that shortly after the start-up, the hydrogen content in the gas phase was quite high, while in the sequence it decreased gradually. From figure 1 it is obvious that hydrogen production rates and yields decreased with the HRT decrease, with the HRT of 24 h giving the higher hydrogen production.

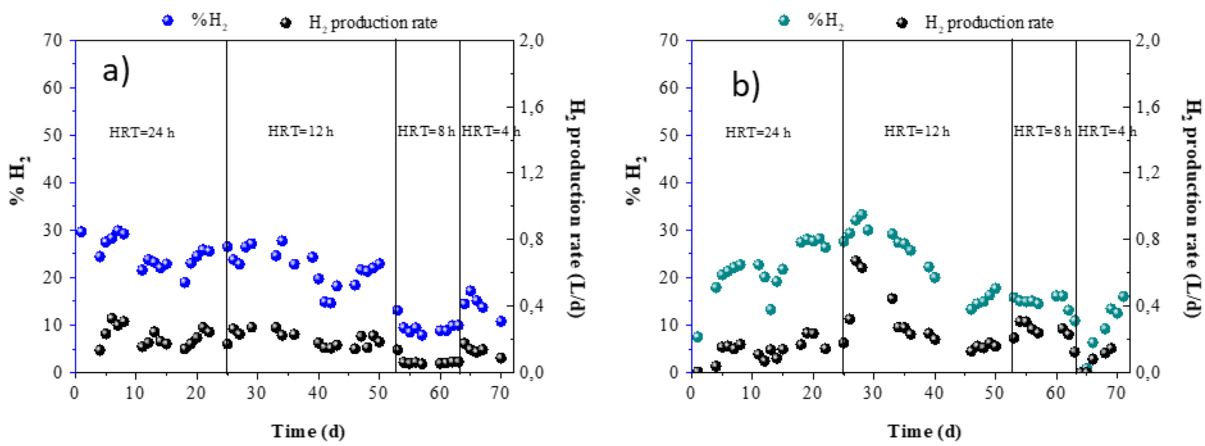

Figure 1: The percentage of hydrogen in the biogas and the hydrogen production rate of a) CSTR-1 and b) CSTR-2

Table 1: The main characteristics of CSTR-1 at four steady states

	HRT=24 h	HRT=12 h	HRT=8 h	HRT=4h
pH	5.82 ± 0.03	5.17 ± 0.09	5.23 ± 0.07	5.43 ± 0.14
TSS (g/L)	4.31 ± 0.27	4.55 ± 0.03	5.17 ± 0.61	6.54 ± 0.39
VSS (g/L)	3.15 ± 0.22	3.43 ± 0.21	4.11 ± 0.52	5.51 ± 0.48
Hydrogen Content (%)	25.12 ± 1.35	22.00 ± 0.68	9.36± 0.63	12.02 ± 1.59
d COD (g/L)	20.42 ± 0.67	18.86 ± 1.08	19.90 ± 0.57	20.72 ± 0.77
% COD (theoretical/measured)	83.24	64.27	57.16	49.73
Hydrogen production rate (L/$L_{reactor}$/d)	0.50 ± 0.09	0.44 ± 0.07	0.14 ± 0.01	0.26 ± 0.05
Hydrogen yield (L H_2/L_{feed})	0.50 ± 0.09	0.22 ± 0.03	0.04 ± 0.00	0.04 ± 0.00
Hydrogen yield (L H_2/kg FORBI)	8.14± 0.57	3.51 ± 0.06	0.73 ± 0.06	0.71 ± 0.00

Table 2: The main characteristics of CSTR-2 at four steady states

	HRT=24 h	HRT=12 h	HRT=8 h	HRT=4h
pH	6.00 ± 0.32	5.72 ± 0.17	5.73 ± 0.12	5.66 ± 0.08
TSS (g/L)	4.82 ± 0.35	4.13 ± 0.84	4.53 ± 0.44	9.11 ± 2.39
VSS (g/L)	3.56 ± 0.22	3.04 ± 0.69	3.23 ± 0.58	7.81 ± 1.26
Hydrogen Content (%)	27.49 ± 0.79	15.88 ± 1.25	15.58 ± 0.67	12.81 ± 1.20
d COD (g/L)	20.44 ± 0.52	18.86 ± 1.04	45.42 ± 4.11	18.98 ± 100
% COD (theoretical/measured)	82.17	66.79	86.21	67.71
Hydrogen production rate (L/$L_{reactor}$/d)	0.42 ± 0.10	0.38 ± 0.05	0.57 ± 0.03	0.38 ± 0.07
Hydrogen yield (L H_2/L_{feed})	0.42± 0.10	0.19 ± 0.02	0.19 ± 0.01	0.06 ± 0.01
Hydrogen yield (L H_2/kgFORBI)	6.73± 1.65	3.10 ± 0.44	1.27 ± 0.16	1.03 ± 0.19

Comparing the results of both reactors, it is obvious that at the HRT of 24 h, similar results regarding hydrogen production were obtained indicating that the possibility of dilution of FORBI with MW instead of tap water could be a promising solution, during fermentation.

Acknowledgements

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References:

Alexandropoulou. M., Antonopoulou, G., Trably, E., Carrere, H., Lyberatos, G. Continuous biohydrogen production from food industry wastes: Optimization of operational parameters and microbial community analysis. J. Clean. Prod. 174 (2018) 1054-1063. https://doi.org/10.1016/j.jclepro.2017.11.078

Sustainable Environmental Management of pig production with an Integral Manure Management System with Constructed Wetlands

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Keywords: Artificial wetlands, pig slurry, soil fertility, greenhouse gases, ammonia gases.

ABSTRACT

The main objective of the Research Chair between the company CEFUSA and the Polytechnic University of Cartagena "Sustainable Environmental Management of Pig Production" is the sustainable management of pig slurry taking into account its composition and aspects related to its efficient use as fertilizer and agricultural water resource. For its management, current and upcoming environmental legislation and the best available techniques recognized by the Ministry of Agriculture, Fisheries and Food are considered under the principles of circular economy and using low-cost techniques. So far, 11 integrated manure management systems with artificial wetlands have been designed, 2 of them operating in real farm conditions. In the management systems, the slurry is subjected to physical and biological treatments (phytopurification) implemented by means of mechanical solid-liquid phase separators, decantation systems and artificial wetlands. The main conclusions of the tests carried out with the artificial wetlands stand out between raw pig slurry and purified pig slurry a reduction of 70% of total nitrogen, 40% of electrical conductivity, 99% of sedimented solids and 60% of GHG and ammonia emissions, together with a reduction of more than 50% of the agricultural area necessary for agronomic recycling. There is also a reduction in odours when working with this type of treatment system associated with the reduction of ammonia concentrations (reaching decreases of up to 40%). With respect to the current research period, tests continue to be carried out with artificial wetlands (currently 5 types of plant species are being used to purify the slurry (*Phragmites australis*, *Nerium oleander*, *Suaeda vera*, *Chrysopogon zizanioides* and *Lygeum spartum*), all slurry fractions, plant and soil fertility, and subsoil studies. The emissions of greenhouse gases and ammonia in manure, slurry and soil in different seasonal periods are also quantified. At the same time, work will be done with special emphasis on the conducting studies with slurry related to obtaining the European RENURE category (Huygens et al., 2020), this category will allow slurry to be valued as conventional mineral fertilizers. In addition, in this new period it is intended to validate the slurry treatment methodology together with the Ministry for Transition Ecology and the Demographic Challenge in order to be recognized as an integral circular economy technique.

References:

Huygens D., Orveillon G., Lugato E., Tavazzi S., Comero S., Jones A., Gawlik B., Saveyn HGM. 2020. Technical proposals for the safe use of processed manure above the threshold established for Nitrate Vulnerable Zones by the Nitrates Directive (91/676/EEC). JRC Sciece For Policy Report.

High and low technological implementation of bio based energy sources in Europe: Comparisons and contrasts

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Keywords: Net Zero, Bioenergy, High Technology, Low Technology, Waste to energy

ABSTRACT

Circular economy is sustainable if only has adapted the climate crises reverse target. Given the above in parallel with average temperature rise, due to anthropogenic greenhouse gasses (GHG) emissions, by 1.1 °C worldwide since 1880, first industrial revolution (1, 2), it has become an imperative need of a multi-lever strategy towards credible decarbonisations actions.

Energy efficiency, circular economy strategy and carbon capture (storage) and utilization can be the three pillars of both small and large scale, low or high-tech, decarbonisation solution for a sustainable future for all (3, 4, 5). Under that perspective biomass, energy solutions can be a circular economic route with a positive contribution on emissions reduction. Bioenergy can be used in solid bioenergy form, as biogas and liquid biofuels in industrial sector, in residential and in transportation sector (5, 6). It has a strong interaction with agricultural, forestry and waste management sectors. In that aspect, there are multiple regulations initiatives in European Union contributing in the net zero (11) target by 2050, among of which are: EU Green Deal, and other European initiatives such as the Circular Economy Action Plan, Bio economy Strategy, Biodiversity Strategy, Farm to Fork Strategy, European Waste Incineration Directive (WID), Forest Strategy and Municipal Circular Economy Action Plans (CEAPs).

Low and high technology differs in the complexity and sophistication of technological systems. Low technology, like the one is used for briquettes and pellets formation, refers to simple tools, techniques, or systems that require minimal knowledge, infrastructure, or resources to create and mostly manually operate, with less efficiency or precision. All the above can make low technology solutions easier to be adapted in different circumstances, decentralized and under lower cost conditions sustainable for small communities. High technology, on the other hand, involves advanced and intricate systems that are often based on cutting-edge scientific and engineering knowledge, requiring specialized skills and significant resources to develop and maintain. High-tech solution are used for biorefineries, biomass pretreatment methods, for advances biomass conversion and the cutting edge bioenergy with carbon capture and storage (BECCS) technology (12, 13).

The linked environmental, economic, and social effects of the production and usage of bioenergy have a wide range of effects that mostly have to do with the degree as well as the application method (8, 9). Synergies between the different technologies and the customized usage of the most appropriate under a sustainable perspective (10) is the circular solution of biomass materials, like forestry residues, sawmill residues, urban prunings and other organic waste, towards a decarbonized future. In this study, real world practices and applications for electricity and heat from biomass are identified and evaluated, using a multicriterial approach, to decarbonisation.

Acknowledgements

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References:

(1) GISTEMP Team, 2023: GISS Surface Temperature Analysis (GISTEMP), version 4. NASA Goddard Institute for Space Studies. Dataset accessed 20YY-MM-DD at https://data.giss.nasa.gov/gistemp/.

(2) Lenssen, N., G. Schmidt, J. Hansen, M. Menne, A. Persin, R. Ruedy, and D. Zyss, 2019: Improvements in the GISTEMP uncertainty model. J. Geophys. Res. Atmos., 124, no. 12, 6307-6326, doi:10.1029/2018JD029522

(3) Wang F., Harindintwali J.D., Yuan Z., et al., (2021). Technologies and perspectives for achieving carbon neutrality. The Innovation 2(4), 100180, doi: https://doi.org/10.1016/j.xinn.2021.100180

(4) Noussan, M., Hafner, M., Tagliapietra, S. (2020). Decarbonization Solutions. In: The Future of Transport Between Digitalization and Decarbonization. SpringerBriefs in Energy. Springer, Cham. https://doi.org/10.1007/978-3-030-37966-7_2

(5) BECoop – Technical catalogue on biomass direct heating, April 2003, available at https://www.becoop-project.eu/wp-content/uploads/Biomass-Direct-Heating-3.pdf

(6) BECoop - Technical catalogue on biomass district heating, January 2022, available at https://www.becoop-project.eu/wp-content/uploads/Biomass-District-Heating.pdf

(7) Wolfgang Cramer, et. al., Climate change and interconnected risks to sustainable development in the Mediterranean. Nature Climate Change, 2018; DOI: 10.1038/s41558-018-0299-2

(8) REPORT: Technology Roadmap Delivering Sustainable Bioenergy, 2017, OECD, available at https://www.ieabioenergy.com/wp-content/uploads/2017/11/Technology_Roadmap_Delivering_Sustainable_Bioenergy.pdf

(9) W Kostakis, V., Pazaitis, A., & Liarokapis, M. (2023). Beyond high-tech versus low-tech: A tentative framework for sustainable urban data governance. Big Data & Society, 10(1). https://doi.org/10.1177/20539517231180583

(10) Nikolaou, I.E., Jones, N., Stefanakis, A.I., 2021. Circular Economy and Sustainability: the Past, the Present and the Future Directions. Circular Economy and Sustainability 1, 1-20, https://doi.org/10.1007/s43615-021-00030-3

(11) Net Zero overview, University of Oxford, available at https://netzeroclimate.org/what-is-net-zero/#:~:text=It%20is%20international%20scientific%20consensus,reaching%20net%20zero%20around%202050.

(12) Timeline: How BECCS became climate change's 'saviour' technology, available at https://www.carbonbrief.org/beccs-the-story-of-climate-changes-saviour-technology/

(13) Ambaye T. G., Vaccari M., Bonilla-Petriciolet A, Prasad S., E. D. van Hullebusch, Rtimi S.,2021. Emerging technologies for biofuel production: A critical review on recent progress, challenges and perspectives,Journal of Environmental Management, 290, 112627, https://doi.org/10.1016/j.jenvman.2021.112627

Decision Support System (DSS) for Controlled Pig Slurry Application and Sustainable Resource Management

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Keywords: DSS (decision Support System), ARD (Agricultural Resource Management and development), Pig slurry (PS), Sustainable management (SM), carbon footprint (CF), water footprint (WF).

ABSTRACT

Pig slurry (PS) is a mixture of pig manure and water, it poses significant challenges in its management within the agricultural sector. The primary issue is the excessive nutrient content of PS, particularly nitrogen and phosphorus. Improper application or overuse of slurry can result in nutrient overload, leading to soil nutrient imbalances and the subsequent risk of nutrient runoff and water pollution. Eutrophication of water bodies, and degradation of aquatic ecosystems are potential consequences. Additionally, the release of odorous gases, such as ammonia and methane during slurry storage and application contributes to air pollution and negatively impacts the environment and the well-being of nearby communities.

The training materials in the DSS in ARD (Decision Support System for Agricultural Resource Management and Development) aimed to create a DSS tool that would act as an intermediary between farmland and livestock farms, specifically focusing on reducing the uncontrolled application of slurry that can pose potential risks to terrestrial and aquatic systems due to the cumulative nature of certain elements and their transfer.

The DSS tool was designed to facilitate the sustainable management of pig slurry by implementing an algorithm with the best possible options available. It aimed to provide farmers with guidance and recommendations on how to optimize the usage of nutrients and fertilizers, increase productivity, and minimize the environmental impact. The overall goal was to promote effective, practical, and economical approaches to managing agricultural resources while addressing issues such as soil erosion and adapting to climate change.

In this research, a set of training materials in DSS and green skills were generated for two zones: Valle de Guadalentín and Cuenca Vertiente al Mar Menor, Murcia Region, Spain. In both location intensive livestock farming reaches high densities, generating large volumes of manure production, which implies a potential risk of contamination due to inadequate management of manure production, storage, and distribution processes. Additionally, those areas have a very intensive agricultural activity, in which some areas have been designated as vulnerable from the point of view of nitrate contamination, which imposes application limits of the PS as a fertilizer.

In this study, we have developed a set of training materials focusing on Decision Support Systems (DSS) and green skills for sustainable agriculture. The training covers various aspects, including collecting input material for the DSS through stakeholder information that was carried out by a questionnaire prepared by the GARSA research group in order to obtain all the information related to the farms. The questionnaire included, among others, REGA (General Registry of Livestock Farms) and other information such as the livestock farm registration, status (active/inactive), typology according to animals, zootechnical classification, address, coordinates (longitude, latitude) and capacity, moreover laboratory analysis of pig slurry samples. It also includes designing and developing a DSS database and data analysis system. Additionally, the training explores the challenges and prospects of employing DSS in Agriculture 4.0, emphasizing evidence-based decision-making and the potential for increased accuracy and user-friendliness. Overall, these materials aim to empower farmers with the knowledge and tools to optimize

resource management, improve productivity, and minimize environmental impacts using the DSS and green skills, and contribute to the overall sustainability of agricultural resource management.

A prototype for DSS in ARD was applied on the two study cases farms to put into practice the benefits that come from the precision application of slurry on farmland. The DSS tools enable the agriculture and agri-food sectors to assess, monitor and reduce the negative impacts of agricultural methods and techniques on the environment. The prototype is focused on the reduction of carbon footprint (CF): the total greenhouse gases (GHG) emitted and the reduction of the water footprint (WF): the total volume of freshwater used to produce services.

By utilizing the DSS, farmers could make informed decisions about when, where, and how to apply slurry to their farmland. The tool would take into account factors such as nutrient content, soil conditions, weather conditions, and environmental considerations to provide tailored recommendations for slurry application. This approach aimed to reduce the uncontrolled and excessive use of slurry, which could lead to nutrient runoff, water pollution, and other ecological problems.

References:

Código de Buenas Prácticas Agrarias de la Región de Murcia (Orden de 3 de diciembre de 2003 de la Consejería de Agricultura y Agua y Medio Ambiente).

Hoeve, M.T. Life cycle assessment of pig slurry treatment technologies for nutrient redistribution in Denmark. J. Environ. Manag. 2014, 132, 60–70.

Karmakar, S., Laguë, C., Agnew, J., & Landry, H. (2007). Integrated decision support system (DSS) for manure management: A review and perspective. Computers and Electronics in Agriculture, 57(2), 190-201.

Krapac, I.G.; Dey, W.S.; Roy, W.R.; Smyth, C.A.; Storment, E.; Sargent, S.L.; Steele, J.D. Impacts of swine manure pits on groundwater quality. Environ. Pollut. 2002, 120, 475–492.

Lopez-Ridaura, S.; van derWerf, H.; Paillat, J.M.; Le Bris, B. Environmental evaluation of transfer and treatment of excess pig slurry by life cycle assessment. J. Environ. Manag. 2009, 90, 1296–1304

Martin, G., Moraine, M., Ryschawy, J., Magne, M. A., Asai, M., Sarthou, J. P., ... & Therond, O. (2016). Crop–livestock integration beyond the farm level: a review. Agronomy for Sustainable Development, 36(3), 1-21.

Zhai, Z., Martínez, J. F., Beltran, V., & Martínez, N. L. (2020). Decision support systems for agriculture 4.0: Survey and challenges. Computers and Electronics in Agriculture, 170, 105256.

Use of techniques to mitigate Greenhouse Gas emissions and ammonia from pig slurry storage

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Keywords: Greenhouse Gas (GHG) emissions, Ammonia emission, Sustainable techniques of management, Storage Pond, Pig slurry management.

ABSTRACT

Pig production has reflected a progressive increase in the number of animals in recent years, especially for fattening pigs (over 50 kg live weight). Within Europe in 2020, Spain ranked first with a livestock production of 32.6 million heads, which had generated a volume of approximately 75 million m3 of slurry in that year. The Region of Murcia, is the fifth autonomous community in Spain in pig production, has a pig census of 2,120,000 heads in the report published in November 2020 (CARM, 2020), representing both economic and environmental repercussions associated with this activity.

Pig slurry storage facilities tend to be sources of emissions for ammonia (NH_3), methane (CH_4), carbon dioxide (CO_2), nitrous oxide (N_2O) and hydrogen sulfide (H_2S) from livestock production (Berg et al., 2006; Kupper et al., 2020).

It is necessary to determine the influence of emissions due to pig farming, since these generate environmental problems that affect water, air and soil, which is ordered by European regulations that member states have to comply with. These directives include Council Directive nitrates (91/676/EEC), European Strategy for Adaptation to Climate Change, Water Framework Directive, etc.

A pilot scale experiment was carried out to test different techniques in order to mitigate greenhouse gases emissions and ammonia and to improve manure fertilizer properties. During one year were studied the GHG and ammonia emissions at a pilot-scale ten storage ponds. It comprised ten plastic storage ponds with a useful volume of 12 m^3, allowing the GHG emissions to be measured from pig slurry after storing under similar conditions to full-scale storage.

The techniques used for the treatment of the pig slurry were, plastic cover, straw cover, acidification, phase separator and aerobic digestion, additives based on bacteria. Additionally, one storage pond was left as a control. Gaseous emissions from the storage ponds were measured using a dynamic chamber during two periods, low and high emissions. The pig slurry sampled for triplicated after each gaseous emissions measuring, and analysed for DM, Tot-N, TAN (APHA, 1992), pH and TSS (Directive 1991/676/EC.).

This research has evaluated the efficiency of the techniques for pig slurry treatment with the aim to measure the emissions and expecting improve the characteristics of the byproduct. Best results have shown that techniques as acidification reached reduction of 70% for CH_4, 44% for CO_2 and 68% for NH_3, the use of microorganism reached a decreasing of 54% for CH_4, 48% for CO_2 and 37% for NH_3. The storage pond with pig slurry from phase separator showed very good results in comparison with others, achieving percentages around 90% for CH_4, 50% for CO_2 and 45% for NH_3.

In storage systems, the reduction of emissions into the atmosphere depends on the technique that is applied and that it is under adequate environmental conditions that allow changes in the physical, chemical and biological properties of the slurry to take place, therefore, these characteristics are directly related to the reduction of GHG and ammonia emissions in these management systems.

In general, it can be noted that nitrogen has been reduced reaching percentages up to 23-65%, on the other hand, in almost all the ponds an increase in STS and EC was verified, due to evaporation.

References:

APHA, AWWA y WPCF. 1992. "Standard Methods for the Examination of Water and Wastewater", 20th edition. Washington, DC. American Public Health Association, American Water Works Association, Water Pollution Control Federation.

Béline F, Daumer M L, Loyon L, Pourcher A M, Dabert P, Guiziou F, Peu P. The efficiency of biological 874 aerobic treatment of piggery wastewater to control nitrogen, phosphorus, pathogen and gas emissions. Water 875 Science & Technology, 2008, 57 (12): 1909-1914 876.

Berg, W., Brunsch, R., Pazsiczki, I. 2006. Greenhouse gas emissions from covered slurry compared with uncovered during storage. Agriculture, Ecosystems and Environment 112: 129–134.

CARM. Consejería de Agua, Agricultura, Ganadería, Pesca y Medio Ambiente. Región de Murcia. https://www.carm.es/web/pagina?IDCONTENIDO=1378&IDTIPO=100&RASTRO=c1415$m1174.

Directive 91/676/EEC of 12 December 1991. Concerning the protection of waters against pollution caused by

Housed livestock, manure storage; manure processing. Draft section for a Guidance Document. 2019.

Kupper, T., Häni, C., Neftel, A., Kincaid, C., Bühler, M., Amom, B., VanderZaag, A. 2020. Ammonia and greenhouse gas emissions from slurry storage - A review. Agriculture, Ecosystems and Environment 300:106963

nitrates from agricultural sources. O
. J. Eur. Commun. 1991, 375, 1–8.

Petersen, A.J. Andersen, J. Eriksen. 2012. Effects of slurry acidification on ammonia and methane emission during storage. J. Environ. Qual., 41 pp. 88-94

Petersen, S.O. 2017. Symposium review: Greenhouse gas emissions from liquid dairy manure: Prediction and mitigation. J. Dairy Sci. 101, 6642–6654.

Petersen, S.O., M. Skov, P. Drøscher, and A.P.S. Adamsen. 2009. Pilot scale facility to determine gaseous emissions from livestock slurry during storage. Journal of Environmental Quality 38:1560-1568.

Technical proposals for the safe use of processed manure above the threshold established for Nitrate Vulnerable Zones by the Nitrates Directive (91/676/EEC), EUR 30363 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-21539-4, doi:10.2760/373351, JRC121636.

Aspects of urban agriculture in the sustainable development - the case of Latvia

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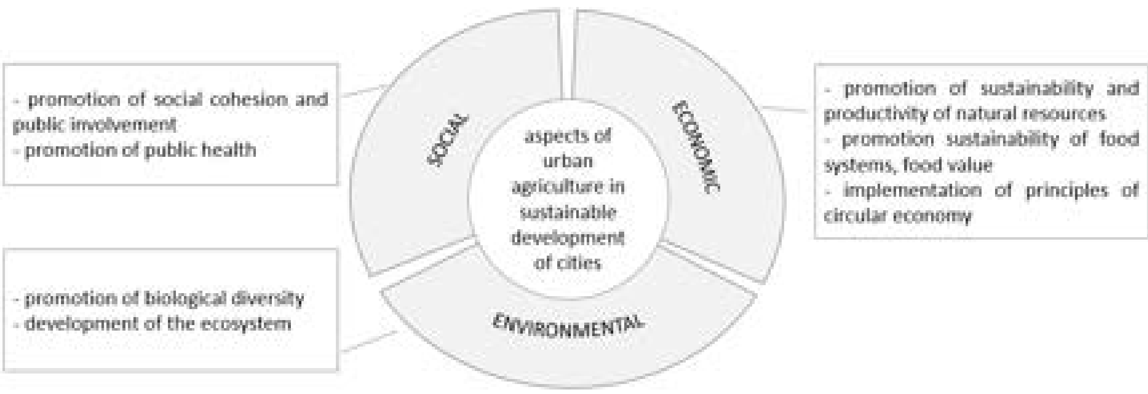
Keywords: urban agriculture, Latvia, sustainable development, sustainable cities

ABSTRACT

The need for a new development concept was determined already in 1987 by the World Commission on Environment and Development, which defined a sustainable development as the most appropriate development concept in the growing globalization (Report of the World…, 1987). Being in the era of globalization and related processes, including the intensification of political and economic relations, Latvia is in a unified development system with Europe - both in the territorial context and politically and economically as a member of the European Union. A systemic and cross-sectoral approach is essential in promoting sustainability, which is able to develop all dimensions of sustainable development in a balanced manner. Urban agriculture, especially its 21st century practice trends, is able to support and promote urban sustainability in various directions. Therefore, the aim of this study is to identify the aspects of urban agriculture that can contribute to the sustainable development of the economics, environment and society of Latvian cities. To achieve the aim, the following tasks have been set: 1) to describe aspects promoting the sustainability of Latvian cities in strategic development documents; 2) to determine the potential of urban agriculture in aspects of urban sustainable development. In order to fulfil the tasks, 32 documents of strategic development were analysed and compared with the determined protentional of urban agriculture (Dobele, Dobele & Zvirbule, 2022) through the functions of the practice. The specificity of the environment determines that practicing agriculture in cities is able to realize a wide range of mutually interacting functions (Dobele, Dobele & Zvirbule, 2022). And in the urban environment, aspects of agricultural practice form a different specificity than in rural or peri-urban areas, also in the context of sustainable development (Dobele, Zvirbule & Dobele, 2021). Urban agriculture studies often analyse the impact of practice on sustainable development and its three dimensions (Wittenberg et al., 2022), so in this study, aspects of urban agriculture in strategic development documents are classified into groups of economic, social and environmental aspects (Figure 1).



Source: authors' construction

Fig.1. *Aspects of urban agriculture in sustainable development of Latvian cities*.

Aspects of urban agriculture can be identified in several directions of sustainability of the **economic dimension**. In order *to promote the sustainability and productivity of natural resources*, two main principles of action have been identified in the study: 1) effective use of natural resources and their balanced development (defined OECD's Recommendation of the Council on Resource Productivity and

Sustainable Development Strategy of Latvia until 2030); 2) transformation of the economy and society, emphasizing and valuing resources (defined in the European Green Deal and the EU's Circular Economy Action Plan). Urban agriculture promotes the awareness of the role of natural resources and the environment in cities and the use of local resources. *The sustainability of food systems and the creation of food value* can be identified in the such strategic development principles as: 1) determining the challenges and aims of the sustainability and resilience of the food system and creating awareness of the value of food (which is primarily defined in the EU strategy "Farm to fork"); 2) promotion of cooperation in value chains and development of short food chains (defined both in the "Farm to Fork" strategy and in the Latvian Bioeconomy Strategy 2030). Urban agriculture promotes the flexibility and autonomy of urban food systems, creates awareness of the value of food systems in cities and ensures short food chains, thereby reducing negative environmental impacts. *The implementation of circular economy principles* as a topicality in sustainable development is defined by the EU's Circular Economy Action Plan, Latvia's Adaptation Plan to Climate Change for the Period until 2030 and the Latvian Bioeconomy Strategy 2030. It can be promoted by urban agriculture in the form of community gardens (by promoting sharing systems) and in households in the process of food production (by learning of circular economy principles). In the sustainability of the **social dimension**, *social cohesion and public involvement* are essential prerequisites. For achieving this in strategic development documents (the UN's Universal Declaration of Human Rights, EU Cohesion Policy, Latvian Guidelines for the Development of a United and Civically Active Society 2021-2027) several directions of action can be identified in which urban agriculture can provide encouraging and supportive aspects: promotion of equality, community and social responsibility, especially in community garden practices (including schools, hospitals and nursing homes), reduction of social exclusion, taking into account the functionality of the practice in uniting different social groups and building the community, and promotion of social and civic participation, especially in the practice of collectively managed gardens. *Promotion of public health* (both psycho-emotional and physical) is updated by several strategic development documents, but in Latvia's situation primarily by Public Health Guidelines 2021-2027. Urban agriculture not only promotes physical activities, but also provides relaxation and stress reduction functions, as well as promotes the inclusion of healthy, fresh food in the nutrition. Urban agriculture has the potential to support the **environmental dimension** of urban sustainability in two directions. In the strategic development documents binding on Latvia, two principles of action for ensuring *biological diversity* in the urban environment can be identified: highlighting and promotion of biological diversity (based on the EU Biodiversity Strategy for 2030 and EU Cohesion Policy) and the interaction of urban and rural environments to improve the quality of life (based on National Development Plan of Latvia for 2021-2027). Urban agriculture significantly develops biological diversity in the city, moreover, the practice of agriculture develops the spatial transfer of food growing traditions and values. However, in promoting the sustainability of the urban environment, the primary is the potential of urban agriculture in *ecosystem services*: the understanding and formation of the ecosystem as the basis of existence and well-being (based on the Latvian Bioeconomy Strategy 2030) and the determination of the relevance of climate neutrality and implementation of the principles (based on the Kyoto Protocol, Latvia's Strategy for Achieving Climate Neutrality until 2050). Taking into account the multi-functionality of urban agriculture, the development of practices in cities contributes to the residents' understanding of the interaction between human and nature, the mitigation of negative environmental changes, such as air temperature and pollution, and the learning of circular principles in promoting climate neutrality.

Urban agriculture has the potential to promote all dimensions of urban sustainability. And, although urban agriculture is not identified in the strategic documents of sustainable development of Latvia, it is able to provide support functions in all dimensions of sustainable development, primarily ensuring the restoration and development of the synergistic connection between human and nature.

References:

Dobele, M., Dobele A., Zvirbule A., 2022. Multifunctionality of urban agriculture and its characteristics in Latvia. Rural Sustainability Research: Scientific Journal of Latvia University of Life Sciences and Technologies, 48 (348), 54-67, https://doi.org/10.2478/plua-2022-0016.

Dobele M., Zvirbule A., Dobele A., 2021. A review of urban, peri-urban and rural agriculture concepts and role in sustainable development. Starptautiskās zinātniskās konferences "Sociālās zinātnes reģionālajai attīstībai 2020" materiāli, 2021. 3.daļa: Ekonomikas aktualitātes. Daugavpils: Daugavpils Universitāte, 59-66. Available: https://du.lv/wp-content/uploads/2022/11/SZF-krajums_III_Ekonomika_2020.pdf.

Report of the World Commission on Environment and Development: Our Common Future, 1987. Retrieved June 7, 2023 from: https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf.

Wittenberg J., Gernert M., El Bilali H., Strassner C. (2022) Towards Sustainable Urban Food Systems: Potentials, Impacts and Challenges of Grassroots Initiatives in the Foodshed of Muenster, Germany. Sustainability, 14 (20), 13595, https://doi.org/10.3390/su142013595.

Enhancing carbon sinks through mangrove afforestation in a coastal constructed wetland park

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Keywords: Carbon Sink, Constructed Wetland, Mangroves, *Avicennia marina*

ABSTRACT

Mangroves play a crucial role as blue carbon ecosystems, and there is growing interest in using mangrove restoration to mitigate greenhouse gas emissions. The Zhongdu Wetland Park in Kaohsiung, Taiwan, was once a natural mangrove habitat along a tidal river but was destroyed due to plywood factory development. The wetland park was established in 2011 through mangrove restoration with the aim of providing regulating and cultural ecosystem services. This study focuses on investigating the carbon sink potential of mangroves in the Zhongdu Wetland Park. The mangrove species in the park include Avicennia marina, Rhizophora stylosa, Lumnitzera racemosa, and Kandelia obovata. Among the mangrove species, A. marina exhibited significantly higher net primary productivity (NPP) and soil carbon burial compared to L. racemosa and R. stylosa, indicating its strong carbon sequestration capabilities. The carbon sink of A. marina in the wetland park were also found to be higher than those observed in natural mangrove habitats, as reported in previous studies. Given its wide distribution range, A. marina is considered the primary contributor to carbon sequestration in the Zhongdu Wetland Park. However, it was noted that A. marina also released the highest CO_2 emissions, possibly due to higher decomposition rates and the input of residential wastewater. Furthermore, negative ecological effects resulting from mangrove expansion, such as river channel narrowing leading to flooding or compression of bare intertidal habitats, have been reported in Taiwan. In conclusion, The mangroves in the Zhongdu Wetland Park function as a carbon sink system, demonstrating the potential for utilizing mangrove restoration in constructed wetland parks to offset future greenhouse gas emissions. This study highlights the importance of considering the ecological engineering strategy of planting mangroves in coastal constructed wetland parks, both for increasing carbon sinks and managing the ecological impacts of mangrove expansion.

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Performance of a denitrifying bioreactor for the treatment of nitrate-laden agricultural drainage water in northeastern Germany

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ABSTRACT

Denitrifying bioreactors are a promising end-of-pipe technology to reduce nitrate losses in the receiving surface waters in agricultural tile-drained landscapes. However, this technology has been barely tested over longer time periods and under Northern German weather conditions. It is unclear, whether the denitrifying processes are operational under cold weather conditions in winter, which is the main discharge season here. A denitrifying bioreactor was installed at a 2.9 ha drainplot alongside a brook in 2017 to test the performance of this technology. The woodchip filter is 20 m long, 3.75 m wide and 2.2 m deep. We recorded weather data (precipitation, temperature, relative humidity), water temperature inside the woodchip filter and flow rates (inflow and outflow) at 15-min time intervals. Additionally, water samples were taken several times a week and analyzed for nitrate, phosphate and total organic carbon concentration (TOC). After six monitoring seasons (November to April) the main results can be summarized as follows. The woodchip filter reduces the nitrate load, which is released to the brook by 50% on average indicating that microbial denitrification takes place in winter at water temperatures of 7.8 °C inside the bio-reactor. Surprisingly, the filter acts also as a sink for phosphorus (ca. 60% load reduction), which is attributed to adsorption processes at organic matter surfaces. However, as a negative side effect, the woodchip filter released organic carbon and the TOC load increased by ca. 60% at the outlet of the filter as compared to the inflow. The results indicate further that the hydraulic retention time is crucial for an optimal management of woodchip filters. Increasing the hydraulic retention time leads to higher nitrate reduction rates and vice versa. Woodchip bio-reactors should be protected against extreme events and related peak flows, which possibly cause bypass flow and hydraulic shear. Our results have shown that hydraulic retention times should be >10 hours to achieve an optimal nitrogen reduction. Overall, denitrifying bioreactors are a low-cost end-of-pipe solutions that have the potential to significantly reduce nitrate pollution in surface waters, if installed widely in agricultural used tile-drained landscapes.

Elimination of Crystal Violet in water by *Pinus patula* biochar: process optimization and validation

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Keywords: Biochar, Crystal Violet, removal, wastewater

ABSTRACT

The discharge of wastewater containing dyes is a source of water pollution that negatively impacts the natural development of aquatic ecosystems and the well-being of organisms (Zhou et al., 2023). Particularly, Crystal Violet (CV) dye is of utmost importance since the exposure to this dye can lead to respiratory and kidney failures, as well as skin irritation, and can cause toxicity in mammalian cells. In addition, CV is described as a recalcitrant, carcinogenic agent; in fact, it is known to promote tumor growth in fish (Bilal et al., 2022). Therefore, this dye should be eliminated from aqueous environments, being adsorption and the use of biochar a technique that has been gaining attention recently because of the ease of operation and low cost of this carbonaceous material (Zhao et al., 2023). Biochar is a solid waste derived from another production processes that is known for its efficiency and sustainability in eliminating dyes in water (Vyavahare et al., 2019).

This study is focused on evaluating the removal efficiency of CV by biochar derived from the gasification of *Pinus patula*. Operational parameters like pH and biochar particle size and level were assessed for the optimization of the treatment. In addition, under optimal conditions, validation studies in a real wastewater matrix were carried out.

For this purpose, a face-centered central composite design of experiments was conducted in a random way to avoid data bias, and a second-order regression model was constructed representing the elimination of the dye of interest from water. Three operating factors were considered: the solution pH (3-9), the biochar concentration (9-18 g/L) and the biochar particle size (150-600 µm). The biochar was previously obtained from wood pellets of *Pinus patula* and characterized as described in Rubio-Clemente et al. (2021) and in Gutiérrez et al. (2021).

The CV adsorption on biochar was analysed through visible spectrophotometry. A DR 2700 visible spectrophotometer (Hach, USA) was used and set at a maximum wavelength of 582 nm to scan the visible spectrum. To determine the concentration of CV in the initial and the treated solutions for each aliquot, a calibration curve was constructed with a coefficient of determination (R^2) of 99,73%. The removal capacity of the biochar over time was calculated as presented in Eq. (1), where the removal of CV is expressed as percentage (%); C_0 refers to the initial CV concentration in solution (mg/L); and C_t is the concentration of CV (mg/L) at time t.

$$\text{Removal of Crystal Violet} = \frac{C_0\text{-}C_t}{C_0} x100 \quad (1)$$

As results, it was obtained that the biochar exhibited remarkable efficiency in eliminating Crystal Violet, achieving a removal efficiency exceeding 99.9% at a dye concentration of 25 mg/L, pH 9, biochar dose of 13.5 g/L, particle size of 300-450 µm, and residence time of 3 min (Figure 1), which were found to be the optimal operating conditions. Additionally, these results were validated in real wastewater generated in a textile industry located in Aburrá Valley, Colombia. It was found that the mineralization in terms of dissolved organic carbon, reached 74.5% within 60 min of treatment.

This study shows that a waste obtained from another production process could be used in the removal of hazardous substances from water. In this regard, not only remediation of polluted wastewater is achieved, but also cleaner production and circular economy are contributed by using a waste to treat waste.

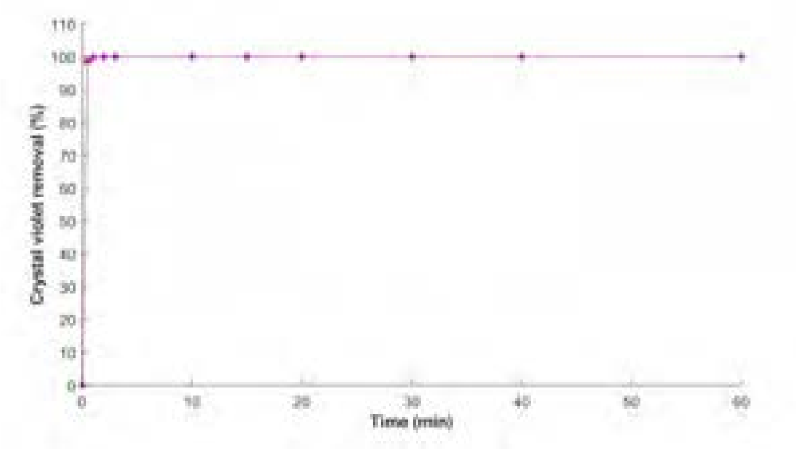

Figure 1. CV removal vs. time by biochar. Operating conditions: CV concentration = 25 mg/L; biochar dose = 13.5 g/L; pH = 3; biochar particle size = 300-450 µm; time = 60 min.

References

Bilal, M., Ihsanullah, I., Shah, M. U. H., Reddy, A. V. B., & Aminabhavi, T. M. (2022). Recent advances in the removal of dyes from wastewater using low-cost adsorbents. *Journal of Environmental Management*, *321*, 115981.

Gutiérrez, J., Rubio-Clemente, A., & Pérez, J. F. (2021). Effect of main solid biomass commodities of patula pine on biochar properties produced under gasification conditions. *Industrial Crops and Products*, *160*, 113123.

Qin, X., Zeng, X., Cheng, S., Xing, B., Shi, C., Yi, G., Nie, Y., Wang, Q., Zhang, C., & Xia, H. (2023). Preparation of double functional carbon-based ZnO derived from rape straw for dye wastewater treatment. *Journal of Water Process Engineering*, *52*, 103588.

Rubio-Clemente, A., Gutiérrez, J., Henao, H., Melo, A. M., Pérez, J. F., & Chica, E. (2021). Adsorption capacity of the biochar obtained from Pinus patula wood micro-gasification for the treatment of polluted water containing malachite green dye. *Journal of King Saud University-Engineering Sciences*.

Vyavahare, G., Jadhav, P., Jadhav, J., Patil, R., Aware, C., Patil, D., Gophane, A., Yang, Y. H., & Gurav, R. (2019). Strategies for crystal violet dye sorption on biochar derived from mango leaves and evaluation of residual dye toxicity. *Journal of cleaner production*, *207*, 296-305.

Zhao, Y., Zhou, H., Song, M., Xu, Z., Sun, Z., Xu, Q., Chen, Y., & Liao, X. (2023). Interface engineering of Ti-MOFs: adsorption of anionic, cationic and neutral dyes in wastewater. *Journal of Molecular Structure*, 135268.

Zhou, H., Ji, S., Zhang, Q., Jin, W., Feng, A., Lin, C., & Li, Q. (2023). Wastewater treatment: A universal, scalable and recyclable catalyst with adjustable activity for diverse dyes degradation. *Journal of Environmental Management*, *330*, 117188.

Life cycle assessment in the production of raw and Fe-modified biochars

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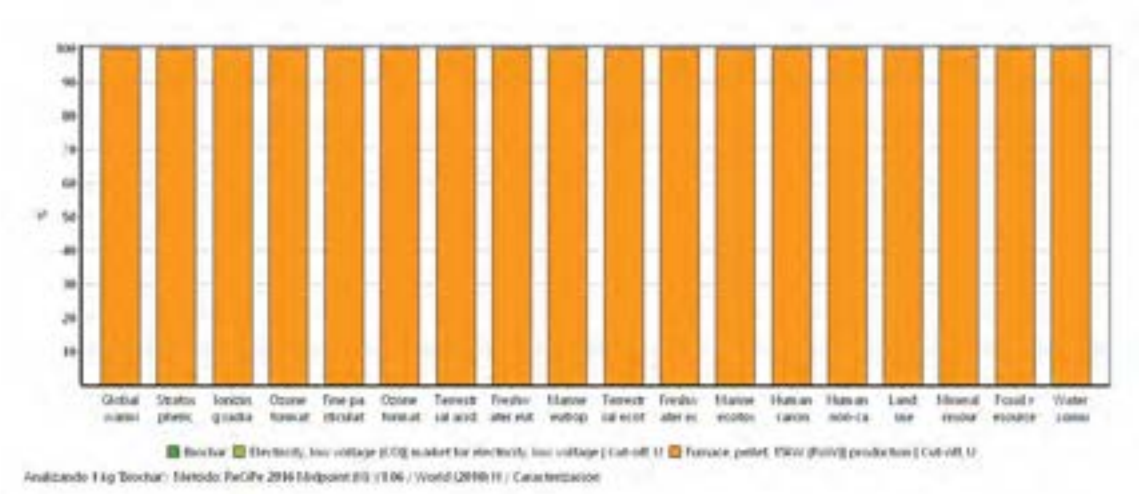
Keywords: circular economy, waste recycling, water treatment, carbonaceous material

ABSTRACT

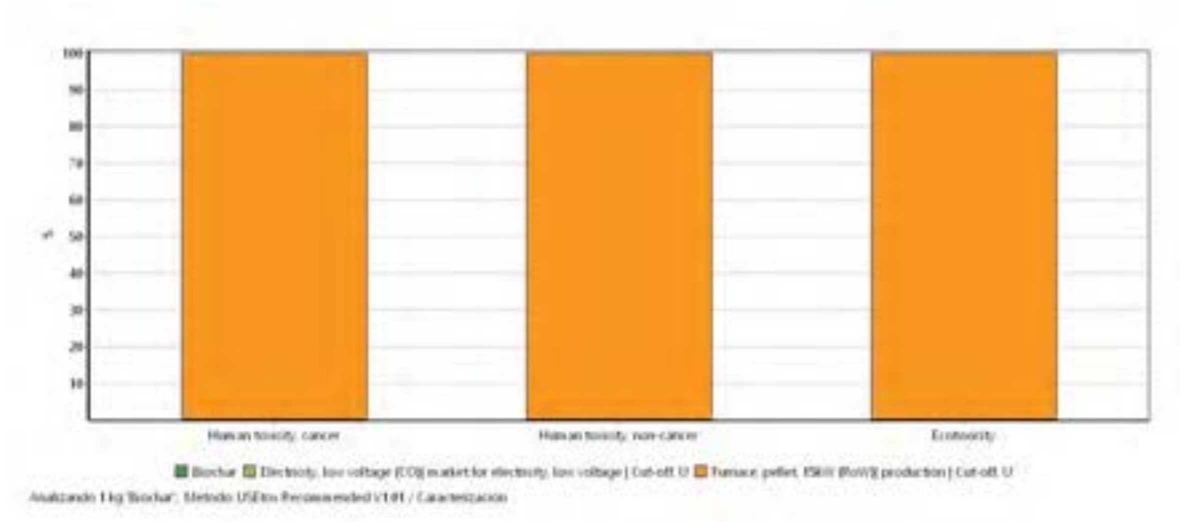
Biochar is a carbonaceous material that has been garnering attention due to its contribution to waste management and circular economy (Nidheesh et al., 2021). Biochar is produced from agricultural, food, and forest waste, sewage sludge, and crops among others (Tian et al., 2023). This waste is a by-product derived from the production of energy by biomass and has been used for the remediation of soil and water treatment (Qian et al., 2023). Biochar has also been modified with metals to increase its use in the treatment of wastewater and to couple it with other water treatment technologies.

In this study, the life cycle assessment of the production of *Pinus patula* raw biochar by gasification was carried out in the software SimaPro 9.3.0.3. (Cui & Shao, 2023) and the ReCiPe 2016 and USEtox methods, to obtain the potential environmental effects of this process and it was compared with the effects of the production ascribed to the iron(Fe)-modified biochar.

The potential environmental effects obtained from the production of *Pinus patula* raw biochar were related to the source of energy for biochar production (Figure 1). In the case of Fe-modified biochar, the potential environmental effects differed only in the stage of the modification of biomass with the metal. These findings provide an insight into the environmental effects linked to the production of raw and modified biochar.



a)



b)

Figure 1. Potential environmental impacts ascribed to the production of biochar by using a) ReCiPe 2016 method and b) USEtox method.

Furthermore, the production of raw and Fe-modified biochars can represent potential environmental effects mainly attributed to the generation of toxic substances during the production of biochar. Hence, further research should be done to study and explain the contribution of biochar to environmental depletion and the toxicity related to its generation and use so that it can be considered to fully contribute to circular economy.

References

Cui, Q., & Shao, F. (2023). Comparison of life cycle assessment for laminating and glazing processes based on simapro. Pigment & Resin Technology, 52(2), 268-272.

Nidheesh, P. V., Gopinath, A., Ranjith, N., Akre, A. P., Sreedharan, V., & Kumar, M. S. (2021). Potential role of biochar in advanced oxidation processes: a sustainable approach. *Chemical Engineering Journal*, *405*, 126582.

Qian, J., Zhou, X., Cai, Q., Zhao, J., & Huang, X. (2023). The study of optimal adsorption conditions of phosphate on Fe-modified biochar by response surface methodology. *Molecules*, *28*(5), 2323.

Tian, W. W., Xu, F., Xing, S. J., Wu, R., & Yuan, Z. Y. (2023). Comprehensive study on the thermal decomposition process of waste tobacco leaves and stems to investigate their bioenergy potential: Kinetic, thermodynamic, and biochar analysis. Thermochimica Acta, 723, 179473.

Greywater treatment with green walls for the washing of reusable cups and bottles

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Keywords: greywater treatment, green walls, reusable plastic cups, nature-based solutions

ABSTRACT

Plastic pollution in the oceans is one of the major environmental issues of the 21st century. The nature of plastic compounds renders them a persistent pollutant that can cause significant adverse effects on marine life and human health (Haward, 2018). It has been estimated that the Mediterranean Sea receives between 150 and 610 thousand tonnes of plastics each year, 94% of which is microplastic debris and 6% microplastics (Sharma et al., 2021). The HORIZON Mission project "REMEDIES" aims to restore, protect and preserve the health of oceans through the monitoring and detection of plastics on the coastlines and surrounding water bodies on the MED region, minimise the presence of plastic litter and microplastics in water and prevent the use of non-degradable plastic in the fishing industry and at businesses located on the coastlines and islands. REMEDIES will also actively promote water circularity and the recovery of resources in 8 demonstration sites across 8 Mediterranean areas.

One of the demonstration sites is the Cyclades Island group at the Aegean Sea in Greece. The Cyclades Island complex is one of Greece's top tourist destinations that attracts millions of tourists yearly owing to its numerous beaches and areas of special natural beauty and biodiversity. The main environmental issues that they are facing are: i) generation of large amounts of plastic waste during the summer months, ii) plastic accumulation due to its transport on currents from other locations and iii) degradation of marine habitats due to plastics and microplastics pollution.

Within the framework of the project and as a means to implement circular solutions for the prevention of plastic waste, a transportable "green" dishwasher system will be developed and installed in Mykonos Island at a beach bar and replicated and possibly modified at the Sea Dance festival in Montenegro. The dishwasher systems will only be used for the washing of reusable cups and bottles. The cups will be developed within the context of the REMEDIES project and as the material, bio-based polymers will be utilised. The produced greywater will be treated to remove solids and pathogens and fed in the built-in vertECO® green wall system to produce high quality reclaimed water that can be recycled back into the dishwasher. The green wall system called vertECO® (vertical ecosystem®) has been developed by alchemia-nova in former projects and has been applied in different contexts for the treatment of wastewater and greywater. This system will be applied as viable technology with low energy and low maintenance requirements, while also providing micro-climate benefits (Fowdar et al., 2017).

In order to further promote the prevention of plastic waste, water condensation systems will be installed in Mykonos Island during the tourist season. Water vapours will be recovered and mineralised by the dehumidifiers, then stored and disinfected to produce high quality water for drinking purposes. The drinking water will be available in water fountains, functioning as bottle refill stations.

It has been calculated that the implementation of these aforementioned solutions will lead to a significant reduction of plastic waste through the deployment of reusable water bottles and cups, the prevention of approximately 140 tons of single-use plastics and the education of roughly 20% of tourists on the Cyclades Islands on zero-waste practices.

Acknowledgements

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References:

Fowdar, H.S., Hatt, B.E., Breen, P., Cook, P.L.M., Deletic, A., 2017. Designing living walls for greywater treatment. Water Research 10, 218-232, https://doi.org/10.1016/j.watres.2016.12.018.

Haward, M., 2021. Plastic pollution of the world's seas and oceans as a contemporary challenge in ocean governance. Nature Communications 9, 667, https://doi.org/10.1038/s41467-018-03104-3

Sharma, S., Sharma, V., Chatterjee, S., 2021. Microplastics in the Mediterranean Sea: Sources, Pollution Intensity, Sea Health, and Regulatory Policies. Frontiers in Marine Science 8, https://doi.org/10.3389/fmars.2021.634934

Integrate management of residues generated from olive cultivation and olive oil production process for soil resource recovery: the “Elaionas” project.

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Keywords: composting, olive mill wastewater, hydrochar, soil fertilization, recycling

ABSTRACT

Olive oil is the most significant agricultural product produced in Greece, as well as in many other Mediterranean countries. Today, it is estimated that approximately 600,000 families earn income from olive cultivation and olive oil production, with over 200,000,000 olive trees being cultivated. Throughout cultivation and olive oil processing, solid residues and liquid waste are generated, leading to environmental pollution and increased production costs. In particular, in olive groves, large quantities of pruned branches (~20 kg/tree/year) are burned, resulting in greenhouse gas emissions and, in some cases, uncontrolled wildfires. Additionally, olive mills produce solid residues (olive leaves, olive pits) and wastewater. Although a small portion of the leaves is used as animal feed, the majority is burned, while the olive mill wastewater is either inadequately disposed of in evaporation ponds or directly released into streams, causing environmental pollution (contaminating groundwater, promoting eutrophication, producing unpleasant odors, etc.).

Simultaneously, the soils of olive groves in the Mediterranean are characterized by low carbon content (Trigo et al., 2009) and are highly susceptible to erosion and subsequent desertification (Ping et al., 2015). Given the current situation, it is essential to increase the organic matter in olive groves to enhance their quality and fertility (Fernandez-Romero et al., 2016). Chipping and incorporating the pruned branches into the soil offer an alternative solution (compared to traditional burning) to reduce CO_2 emissions and minimize organic matter loss from olive orchards. However, this practice significantly increases the risk of disease and insect dispersion in the fields (Benyei et al., 2018). On the other hand, composting these residues before incorporation results in the production of high-quality stabilized organic material, free from pathogens (Ghoneim et al., 2017). Moreover, the liquid waste from olive mills contains significant amounts of nutrients (mainly nitrogen and potassium) that, with appropriate treatment, could also be incorporated into the soil for the benefit of crops (Galliou et al., 2018). Additionally, studies have demonstrated that using olive biochar as a soil amendment constitutes a valuable tool for climate change adaptation (Stavi et al., 2003). The biochar produced from olive tree prunings contains high levels of nutrients and exhibits a high cation exchange capacity compared to other materials (Alburquerque et al., 2016)."

Figure 1. Integrated management system of residues from olive cultivation and olive oil production process aiming at their utilization for the production of soil amendments (compost, biochar) that are returned to the olive groves.

In this context, the "Elaionas" project aims to address these significant issues using ecological methods in both the olive grove (by utilizing olive tree prunings) and the olive mill (by reusing olive leaves and liquid waste), with a cost-effective approach that benefits the cultivation itself. The project involves incorporating the residues, after processing, into the soil to enhance its individual fertility parameters. Specifically, the proposed process (Figure 1) involves utilizing residues from olive cultivation and olive oil production to produce compost and biochar/hydrochar. These valuable products are then returned to the olive grove, aligning with the principles of the Circular Economy model.

The project will be implemented in two regions of Greece renowned for their rich tradition in olive cultivation: Lesvos Island and Crete Island. Specifically, the olive tree prunings from selected pilot olive groves in these areas will undergo chipping and composting before being incorporated into the soil. To maintain proper moisture levels in the composting piles, the supernatant liquid from the olive mill wastewater settling tank will be utilized. It is important to note that the exothermic nature of composting can lead to significant moisture loss, necessitating the addition of water. While irrigated olive groves can receive this replenishment, non-irrigated groves may not be able to due to limited water availability. The innovative process proposed in this project involves utilizing the liquid waste from the olive mill after settling to regulate moisture in the composting piles. Additionally, at the olive mill, the sludge from the settling tank will co-compost with olive leaves to produce high-quality compost, which will also be applied in the cultivations.

Furthermore, the biochar residue produced from the charcoal production process of olive tree prunings will be incorporated into the cultivations. Enriching soil amendments with biochar is of particular interest due to its beneficial characteristics. Moreover, the production of hydrochar from the olive mill wastewater will be examined using the hydrothermal carbonization process. Following these steps, the soil amendments will be applied in olive groves located in Crete and Lesvos. The olive groves will be closely monitored for approximately two years to assess the benefits for the olive tree system. These anticipated benefits encompass improved soil quality (e.g., increased organic matter and essential macro-nutrients such as N, P, K; enhanced water retention capacity, improved soil porosity leading to better aeration, etc.) and increased biodiversity (e.g., greater biomass of soil microorganisms and heightened diversity of plant species in the undergrowth).

In conclusion, the project aims to foster the development of an enhanced process for the integrated management and utilization of residues from olive cultivation and olive oil production, positively impacting both olive cultivation and the environment.

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References:

Alburquerque, J. A., Sánchez, M. E., Mora, M., & Barrón, V. 2014. Slow pyrolysis of relevant biomasses in the Mediterranean basin. Part 2. Char characterisation for carbon sequestration and agricultural uses. J. Cleaner Production, 120, 191–197.

Benyei, P., Cohen, M., Gresillon, E., ...Alonso-Roldán, M., Espadas-Tormo, I. 2018. Pruning waste management and climate change in Sierra Mágina's olive groves (Andalusia, Spain). Regional Environmental Change, 18(2), 595–605

Fernández-Romero, M.L., Lozano-García, B., Parras-Alcántara, L., Collins, C.D., Clark, J.M., 2016. Effects of land management on different forms of soil carbon in olive groves in Mediterranean areas. Land Degrad. Dev. 27, 1186–1195

Galliou, F., Markakis, N., Fountoulakis, M.S., Nikolaidis, N., Manios, T. 2018. Production of organic fertilizer from olive mill wastewater by combining solar greenhouse drying and composting. Waste Management, 2018, 75, pp. 305–311

Ping, C.L., Jastrow, J.D., Jorgenson, M.T., Michaelson, G.J., Shur, Y.L., 2015. Permafrost soils and carbon cycling. Soil 1, 147–171.

Stavi, I., Lal, R., 2013. Agroforestry and biochar to offset climate change: a review. Agron. Sustain. Dev. 33, 81–96

Trigo, C., Celis, R., Hermosín, M.C., Cornejo, J., 2009. Organoclay-based formulations to reduce the environmental impact of the herbicide diuron in olive groves. Soil Sci. Soc. Am. J. 73, 1652–1657.

Introduction of aquaponic farms partly supplied by rainwater into the urban tissue - possibilities, barriers, limitations and challenges

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Keywords: aquaponics, rainwater, climate change, water insecurity, food security, water energy nexus

ABSTRACT

Water security and water safety and food security are among the priority research topics. Both the current geopolitical situation in Europe as well as the ongoing climate change and its effects, particularly unfavorable in large settlement units, force us to take fast steps to ensure safety for city dwellers in terms of access to water and food. In view of the threat of war and terrorist attacks, as well as excessive heat or urban flash floods, also the critical infrastructure of cities should be subject to special protection. This need is reflected both in the legal acts of the European Union - the CER Directive - Critical Entities Resilience (Directive on the resilience of critical entities, 2022), and in the regulations of individual countries, for instance, in Poland (Crisis Management Act, 2007). The sectors from which critical entities will be designated include drinking water, and food production, processing and distribution.

Hydroponics and aquaponics have recently become more and more popular forms of food production. The idea of urban farming is also disseminating. An aquaponic farm, assuming the use of rainwater, nature based solutions (NBSs) and energy from renewable sources, may turn out to be a way to increase the safety of city inhabitant, and their resilience, as well as transition of settlement units. For these reasons, the co - creation of the green-garden installation for the food production, which is based on aquaponic systems supported on rain, together with the public, was the goal of the USAGE research project based on the application (Pala K. et al., 2020). Introducing aquaponic farms partially fed with rainwater into the urban fabric opens up many possibilities for adapting cities and increasing the safety of its dwellers. However, this process encounters a number of limitations and even barriers. There are also problems and difficulties that are a challenge to take on the way to the cities of the future. The aim of the article is to analyze the possibilities, limitations, barriers and challenges arising in the implementation of aquaponic farms in the city.

The research material was a real process of introducing an aquaponic farm (including, among others, preliminary research and analysis and co-design) into the tissue of one of the Polish cities. In addition, the material for the analysis was also data on rainfall in one of the Polish cities for the years 2016-2021 obtained from the Institute of Meteorology and Water Management - National Research Institute (IMGW - PIB), as well as literature data on the quality of rainwater, and rainwater runoff from green roofs in Poland and in the world. The analysis was carried out on the basis of the implementation process, applicable legal acts (differing between individual countries), scientific literature, studies, documents and instructions, and based on the knowledge and experience of members of the interdisciplinary research team in the field of, among others, architecture, economics, environmental engineering (water and sewage technology as well as water supply and sewage systems), biotechnology.

The prepared scientific study may support the preparation of a road map for next investments of this type. It is also a base of tips and suggestions on which aspects should be paid special attention to, which can significantly extend the investment process, disrupt it or even block it. The article also discusses the issues

that today constitute challenges for introducing this type of farms to cities and indicates the directions of action in order to facilitate their adoption and effectively deal with them in the cities of the future.

Acknowledgements

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References:

Directive (EU) 2022/2557 of the European Parliament and of the Council of 14 December 2022 on the resilience of critical entities and repealing Council Directive 2008/114/EC (Text with EEA relevance), OJ L 333, 27.12.2022, p. 164–198, available at http://data.europa.eu/eli/dir/2022/2557/oj, access on 15.07.2023

Ustawa z dnia 26 kwietnia 2007 r. o zarządzaniu kryzysowym, Dz.U. 2007 nr 89 poz. 590 wraz z późniejszymi zmianami

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Applications of circularity and the WEFE Nexus across the Mediterranean: the four Demo Sites of the SureNexus project.

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Keywords: WEFE nexus, nature-based solutions, bioeconomy, demo sites, demos

ABSTRACT

Accelerated climate change has exacerbated the existing environmental concerns in the Mediterranean region due to changes in land use, increased pollution, and decreased biodiversity (Lucca et al., 2023). Current change and future scenarios consistently point to large and increasing climate risks in most impact domains including water, energy, food and ecosystems, the four elements that form the WEFE nexus (Carmona-Moreno et al., 2019; Carvalho et al., 2022; Nika et al., 2022). The Prima foundation funded project SureNexus supports informed and evidence-based decision-making towards a fair transition to climate change adaptation and mitigation in the Mediterranean region through applying the WEFE Nexus approach. Within the project, the WEFE Nexus is implemented and examined at four (4) demonstrators of Nature-based (NBS) and Bioeconomy (BES) solutions in four (4) countries across the Mediterranean. The aim of this poster is to present the four (4) demonstrators and analyse how the WEFE Nexus is applied in each of them, while also outlining the use of NBS, BES and circular economy principles in each demo site.

The first demonstrator is a vineyard and winery site established in the Penedès region in Spain (Cordoniu). It includes three (3) demo sites which test the treatment of winery wastewater using constructed wetlands for agriculture diffuse pollution control. In all three cases, cork by-product granulates are used as a filter medium. Expected impacts include the reduction of diffuse pollution from agriculture, specially from nitrates and the use of waste by-products from agriculture with wastewater treatment and reuse, as an example of the WEFE Nexus.

The second demonstrator is located on Tinos Island (Cyclades) in Greece. It includes two (2) demo sites with the aim to demonstrate solutions towards sustainable tourism. The demo site operating near the Agios Fokas beach is a low-cost, nature-inspired, solar driven desalination system based on the principles of evaporation and condensation, that produces freshwater and salt from saltwater and brine. The produced water is used to irrigate a nearby greenhouse where fruits and herbs are grown. The overall goal of this demo is to demonstrate the benefits of Nature Based Solutions and Bioeconomy Practices embedded in a holistic management and design, as well as to corroborate that small-scale farming and production systems are viable and beneficial to local society and ecosystems. The second demo site is the Tinos Ecolodge, an off-grid ecotourism facility where various water conservation and water/wastewater management practices are applied. Water loops are integrated within a remote agro-eco-touristic facility hosting up to 12 people. All water infrastructure is equipped with quality (EC, PH, Turb, Temp) and quantity (flow or level) sensors. The whole enterprise runs on regenerative electricity through an off-grid photovoltaic and battery storage system.

The third demonstrator is a citrus field located at the Menzeh Experimental Station of INRA Morocco (Regional Center of Kenitra), in the Rabat-Salé-Kénitra region. The objective of the citrus demo site is to improve the quality of national production through a suitable digital technical itinerary towards citrus varieties with good quality. All the implemented strategies converge towards a reduction in the total cost of production of citrus fruits, allowing an improvement in the productivity and competitiveness of the citrus sector. The main strategies include the use of drones for foliar fertilization and phytosanitary treatments, the assessment of UAV-imaging performance to optimize nutrient management of citrus, the irrigation controlled by digital sensors for the rational use of water resources, the use of solar energy in water pumping, the use of digital tools for monitoring the maturity of the fruits of the citrus platform and remote use of the iSCOUT digital tool for monitoring the evolution of the insect population.

The fourth demonstrator is an agrovoltaics field where renewable energy is used for agricultural activities. It is located at the Emek HaMaayanot - Ma'alé Gilboa KKL testing site in Israel. Three (3) types of agricultural categories are grown in the field: orchards, field crops, and vegetables. The demo site examines several advanced methods of energy production through three (3) different photovoltaic systems: static system, single-axis tracker, and two-axis tracker (6.5 ha). Specifically, 3 ha of orchards are grown under static system, 2.5 ha under single-axis tracker, and 2.5 ha under two-axis tracker. The field crops cover 5.5 ha (2.5 single-axis, and 3 ha two-axis). Finally, the vegetable field covers 2 ha (1ha single-axis and 1 ha by two-axis).

This poster presents the design and function of the aforementioned four (4) demonstrators, outlining the WEFE nexus and circularity interactions, through the NBS and BES employed as applied solutions in different contexts, across the Mediterranean.

Acknowledgements

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References:

Carmona-Moreno, C., Dondeynaz, C. and Biedler, M. eds., 2019. *Position Paper on Water, Energy, Food and Ecosystems (WEFE) Nexus and Sustainable Development Goals (SDGs)*. Publications Office of the European Union.

Carvalho, P.N., Finger, D.C., Masi, F., Cipolletta, G., Oral, H.V., Toth, A., Regelsberger, M. and Exposito, A., 2022. Nature-based solutions addressing the water-energy-food nexus: Review of theoretical concepts and urban case studies. *Journal of Cleaner Production*, *338*, p.130652.

Nika, C.E., Vasilaki, V., Renfrew, D., Danishvar, M., Echchelh, A. and Katsou, E., 2022. Assessing circularity of multi-sectoral systems under the Water-Energy-Food-Ecosystems (WEFE) nexus. *Water Research*, *221*, p.118842.

Lucca, E., El Jeitany, J., Castelli, G., Pacetti, T., Bresci, E., Nardi, F. and Caporali, E., 2023. A review of Water-Energy-Food-Ecosystems Nexus research in the Mediterranean: evolution, gaps and applications. *Environmental Research Letters*.

BIODAPH2O – Investigating a novel system for tertiary wastewater purification

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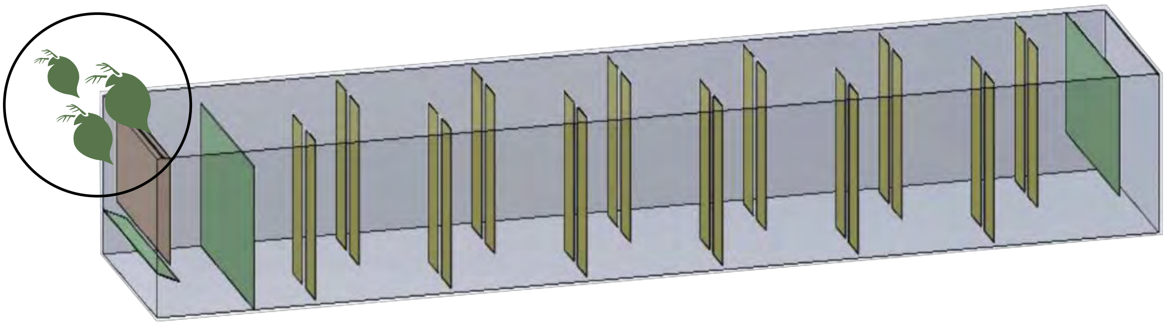
Keywords: Daphnia; nature-based tertiary treatment, water reuse, micropollutant removal



INTRODUCTION

The project aims to demonstrate the effectiveness of BIODAPH technology, an eco-efficient and nature-based tertiary treatment for wastewater, in producing reclaimed water by minimizing the dependence on conventional energy sources, in the context of circularity and green economy. The technology will be applied in existing wastewater treatment plants to further eliminate pollutants and pathogens that would be discharged in freshwater ecosystems or reused in agriculture. The BIODAPH technology combines the filtration capacity of zooplankton (i.e., Daphnia) with the capacity of bacterial and algal biofilm to remove nutrients. In previous studies, it has been demonstrated that Daphnia can remove particles with a size lower than 30 µm, that do not settle or settle too slowly in secondary clarifiers. The removal of solids is associated with a decrease in organic matter and pathogens such as coliforms and *E. coli* from secondary treated wastewater. However, Daphnia is sensitive to common contaminants when they are at raw wastewater levels (e.g., high organic matter, ammonium and nitrite and metals concentration) and, thus, the integration of zooplankton in wastewater treatment lines can be of use only as tertiary treatment (Pous et al. 2020). Regarding organic micropollutants, daphnia filtration has been very efficient (80% average) in the removal of pharmaceuticals and personal care products (Matamoros et al. 2012). As for microplastics and since Daphnia are efficient filters for suspended solids, it shall be expected that they are efficient filters micro plastics as well, as indicated by laboratory experiments (Colomer et al. 2019). No data is available on the performance of Daphnia filtration for the removal of PFAS or antibiotic resistant genes yet.

MATERIALS & METHODS

The project aims to rescale the 1.5 m^3 cylindric reactor, previously developed within the framework of the INNOQUA project (https://innoqua-project.eu/), to a 100 m^3 reactor. Two large-scale reactors will be connected to an activated sludge secondary treatment at Quart (Girona, Spain) to treat 200 m^3/d, whereas in the case of Antissa (Lesvos Island, Greece), a reactor able to treat 10 – 50 m^3/d will be connected to a treatment system that combines an Upflow Anaerobic Sludge Blanket reactor (UASB) with a two-stage vertical sub-surface flow (VSSF) constructed wetlands system (https://www.hydrousa.org/). The target is the reclamation of 146000 m^3 irrigation water at the Spanish site and 13200 m^3 at the Greek site. Both wastewater treatment plants treat domestic/municipal wastewater.

The optimization of the key design factors of the BIODAPH reactor will be carried out by monitoring its efficiency in terms of the biological, microbiological, and chemical quality of the effluent to meet the standards set in Water Framework Directive of the EC (Directive 2000/60/EC and the requirements for agricultural irrigation in accordance with EU directive 2020/741 as well as to reduce the discharge of contaminants of emerging concern such as pharmaceuticals and micro plastics to the aquatic media. The sustainability assessment (environmental LCA, techno-economic LCC, and socio-economic S-LCA) impacts of the technology will be assessed. The feasibility of the process will be evaluated using environmental technology verification (ETV). An economic validation, including the exploitation and the business plan and the assessment of the transferability and replicability of the BIODAPH technology, will also be performed.

EXPECTED RESULTS

- Demonstration of the capacity of the BIODAPH technology for removing emerging pollutants: ~ 70%, for pharmaceuticals, ~ 90% for antibiotic microbial resistance (AMR), 80% for micro plastics, and ~ 60% for perfluoroalkyl substances (PFAs).
- Demonstration of the capacity of the BIODAPH system to reach the standards set in national wastewater reuse guidelines and recent EU regulations (2020/741 of the European Parliament) on minimum requirements for water reuse (PE/12/2020/INIT) recovery and recycling of resources by discharging reclaimed water with low nutrient content (~-50%) and reducing by between 90-99% regulated microbiological parameters.
- Production of reclaimed water with improved quality to reduce the impact generated by the discharge of treated sewage waters in the River Onyar at the Spanish site and to reduce the use of freshwater or potable water for agricultural irrigation and the environmental impacts associated with wastewater release into the aquatic media at the Greek site.
- Reduction of more than 90% of the energy consumption and of more than 80% of the carbon footprint and greenhouse gas production in comparison with conventional tertiary wastewater treatments.
- Significant reduction in operating costs (OPEX) as the treatment is free from chemicals and is less energy intensive.

AGNOWLEDGEMENTS
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REFERENCES

Colomer J., Müller M.F., Barcelona A., Serra T. 2019. Mediated food and hydrodynamics on the ingestion of microplastics by Daphnia magna. Environmental Pollution, 252, 434.

Matamoros V., Sala L., Salvadó V. 2012. Evaluation of a biologically based filtration water reclamation plant for removing emerging contaminants: A pilot plant study. Bioresource Technology, 104, 243.

Pous N., Hidalgo M., Serra T., Colomer J., Colprim J., Salvadó V. 2020. Assessment of zooplankton based eco-sustainable wastewater treatment at laboratory scale. Chemosphere, 238, 124683.

Carbon dioxide sequestration and microalgae biomass production using cheese whey

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Keywords: Cyanobacteria, biofixation, Dairy waste, biomass, circular economy

ABSTRACT

Microalgae are unicellular aquatic microorganisms. Their size ranges from 0.2μm to several millimeters, while over 50,000 different strains have been classified. Microalgae are known for their ability to photosynthesize, converting sunlight and carbon dioxide (CO_2) into organic compounds, without extra energy addition or consumption and without secondary pollution. Thus, CO_2 fixation via microalgae is a potential and promising method for CO_2 capture and storage [1].
The strain *Arthrospira* (Spirulina) *platensis* is a prokaryotic cyanobacterium that can be cultivated at a large scale, both outdoors and indoors. It is an appealing strain for CO_2 capture due to its high growth rate, its durability, and its ability to biofixate CO_2 from exhaust gases, which serve as carbon source in photosynthesis, since the concentration of CO_2 in the atmosphere (0.003%-0.06%) is not sufficient feed for the culture. Approximately, about 1.8kg of CO_2 can be absorbed by 1kg of algal biomass [2, 3]. In this study, spirulina biomass could potentially be utilized to produce first-generation liquid biofuels like biodiesel (via transesterification), biogas (via anaerobic digestion) and bioethanol (via fermentation), as well as in photobiological hydrogen production [4-6].
Microalgae cultivation in photobioreactors is a promising method for carbon dioxide (CO_2) capture and sustainable biofuel production in the context of circular economy. The aim of this study is to investigate the parameters affecting the growth of microalgae biomass in whey-rich solutions and the ability of the strain *Arthrospira* (Spirulina) *platensis* to biofixate CO_2. Experiments were conducted in two different bioreactors: a vertical surface airlift photoreactor (PBR) and a cylinder photobioreactor by Peschl Ultraviolet GmbH (Figure 1).

***Figure 33** a). (Left) The culture in the flat photoreactor on the day of the start-up, b). The culture during the 5th day of operation of the photoreactor (PBR Reactor – Cultivation with CO_2 feed) c). Depiction of the cylinder photobioreactor by Peschl Ultraviolet GmbH*

The effect of different whey dilution ratios and irradiation conditions on biomass productivity was studied in the flat photoreactor (Figure 1a, 1b) in the first two experimental sets (14 days each) under

continuous illumination and light/dark cycles. The results show that the 10% (v/v) whey cheese concentration performed best in both experimental lighting sets, continuous light/dark cycles. The highest biomass production (1.06 g/L) was achieved in 14-day experiments at pH 10.5 and with a 12-h dark/light photoperiod. In the light/dark cycle culture, approximately 85% COD removal and 70% NO^{-3} – N consumption was observed. As a next step (third experimental set), the culture was supplied with CO_2 (1ml/min flow) and better performance was observed (in terms of optical density). The conditions of the experiment were continuous illumination (24 hr) at pH 9.5, 29°C, 200μmol photons/m^2/s light intensity and continuous stirring with air supply to the photobioreactor.
During the second experimental set (cylinder photobioreactor – Figure 1c), the temperature was monitored manually, over the course of 12 hours, before loading the reactor with biomass. A cooling water system was applied to the outside of the lamp to avoid overheating. The temperature inside the reactor ranged from 29 °C to 31.5 °C and the water's temperature in the cooling system's exit from 28 to 32 °C, in accordance with the desired conditions for microalgae cultivation. A first round of experiments has been conducted to determine whether the cultivation in the cylinder reactor was possible without a CO_2 feed. The reactor was loaded with 100ml recultivated spirulina and 500ml Zarrouk medium. The reactor worked for 7 days, in 12-hour cycles using an analog timer. Every day, a sample was taken from the reactor to measure temperature, pH, and absorption. The temperature didn't exceed 31 °C or lower than 29 °C and pH was around 10.4, both favorable conditions for the culture.
Concurrently, *Arthrospira platensis* biomass production presents interest, due to the low cost associated with the nonsterile nature of the cheese whey waste and the utilization of the whey waste as a nutrient for growth. Future work includes the study of how the presence of CO_2 affects the microalgae culture, namely its tolerance limits and the conversion of the produced algal biomass to biofuels.
Keywords: Cyanobacteria, biofixation, Dairy waste, biomass, circular economy

Acknowledgements
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References

[1]. Vale, M. A., Ferreira, A., Pires, J. C. M., & Gonçalves, A. L. (2020). CO_2 capture using microalgae. In Advances in Carbon Capture (pp. 381–405). Elsevier, https://www.sciencedirect.com/science/article/pii/B9780128196571000177
[2]. Adnan AI, Ong MY, Nomanbhay S, Show PL. Determination of Dissolved CO_2 Concentration in Culture Media: Evaluation of pH Value and Mathematical Data. Processes. 2020; 8(11):1373. https://doi.org/10.3390/pr8111373.
[3]. Vale, M. A., Ferreira, A., Pires, J. C. M., & Gonçalves, A. L. (2020). CO_2 capture using microalgae. In Advances in Carbon Capture (pp. 381–405). Elsevier. https://www.sciencedirect.com/science/article/pii/B9780128196571000177
[4]. Athanasiadou V., Klontza E.E., Dimitriou-Christidis P., Fountoulakis M., Lekkas D.F. (2023), Evaluation of *Arthrospira* (Spirulina) *platensis* growth on cheese whey in the context of circular economy, *Sustainable Chemistry and Pharmacy*, 34, 101173, https://doi.org/10.1016/j.scp.2023.101173
[5]. Papadopoulos, K. P., Economou, C. N., Markou, G., Nicodemou, A., Koutinas, M., Tekerlekopoulou, A. G., & Vayenas, D. V. (2022). Cultivation of Arthrospira platensis in Brewery Wastewater. *Water (Switzerland)*, *14*(10). https://doi.org/10.3390/w14101547
[6]. Pereira, M. I. B., Chagas, B. M. E., Sassi, R., Medeiros, G. F., Aguiar, E. M., Borba, L. H. F., Silva, E. P. E., Neto, J. C. A., & Rangel, A. H. N. (2019). Mixotrophic cultivation of Spirulina platensis in dairy wastewater: Effects on the production of biomass, biochemical composition and antioxidant capacity. *PLoS ONE*, *14*(10), 1–17. https://doi.org/10.1371/journal.pone.0224294

Short-term effects of non-tillage on soil health restoration in Mediterranean environments

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Keywords: soil health; microbial biomass carbon; enzyme activity.

Introduction

In recent years the deterioration of soil health is the consequence of intensified conventional agricultural practices, threatening the resilience of agroecosystems to climate change and hence their economic viability. Soil health degradation is especially alarming in arid or semi-arid regions where inputs of organic matter, a major determinant of soil health, are lower due to constraints imposed by water scarcity. Decline in soil organic matter (SOM), decrease of fertility and loss of biodiversity are some of the effects on soil health. Soil organic matter is directly related to soil health and fertility, while being the primary source of energy for soil microbiota and a key contributor to nutrient cycling and availability in agroecosystems. Conventional agriculture applies tillage and is deemed to accelerate the SOM loss through increase accessability of SOM to microorganisms and erosion (Pisante et al., 2014). Contrary to conventional, conservation agriculture aims to promote sustainable and environmentally friendly practices on the bases of minimal soil disturbance, permanent soil cover, crop rotation and diversification. Non-tillage has been extensively used worldwide to restore soil health and SOM, but its benefits in semi-arid environments remain questionable. To improve our understanding on the drivers regulating SOM cycling in semi-arid landscapes, we set up two experimental olive orchards subjected to conventional (tillage and chemical weed management) and conservation (non-tillage) management, and studied the chemical and biological properties of the soil. The main objectives of this work include the investigation on the effect of conservation practices on soil biochemistry, and the gathering of information on the seasonality of these effects imposed by the strong variation of soil moisture and temperature.

Methodology

Soil was sampled for three consecutive seasons: autumn (October 2022), winter (February 2023) and spring (April 2023). Sampling included two fields with olive trees: both Site 1 and Site 2 have been shifted to non-tillage in 2021, including conventional (tillage) and conservation (non-tillage) agronomic managements. The potential enzyme activities of β-glucosidase and phosphatase were fluorometrically measured (Bell C. W. et. al, 2013) for each experimental field subjected to different treatments. Soil microbial biomass carbon (MBC) was determined using the chloroform fumigation-extraction method on sieved (2mm) field-moist soil. Chemical properties of each experimental field was assesed using standard methods of analysis. Such chemical properties include soil organic carbon (SOC), phosphate (PO_4^{3-}), nitrate nitrogen (NO_3-N), electric conductivity (EC), and pH.

Results

Table 17: Chemical properties of the sites (winter sampling).

Sites	Treatments	SOC (g/kg)	PO43- (mg/kg)	NO3-N (mg/kg)	EC (dS/m)	pH
1	Conservation	19.2	28.1	33.9	33.9	7
	Tilled	15.5	9.8	13.1	13.1	7.1
2	Conservation	11.1	33.5	6.5	6.5	7.2
	Chemical	8.5	20.1	20.1	4.1	7.2

	Tilled	19.6	34.1	34.1	8.3	7.2

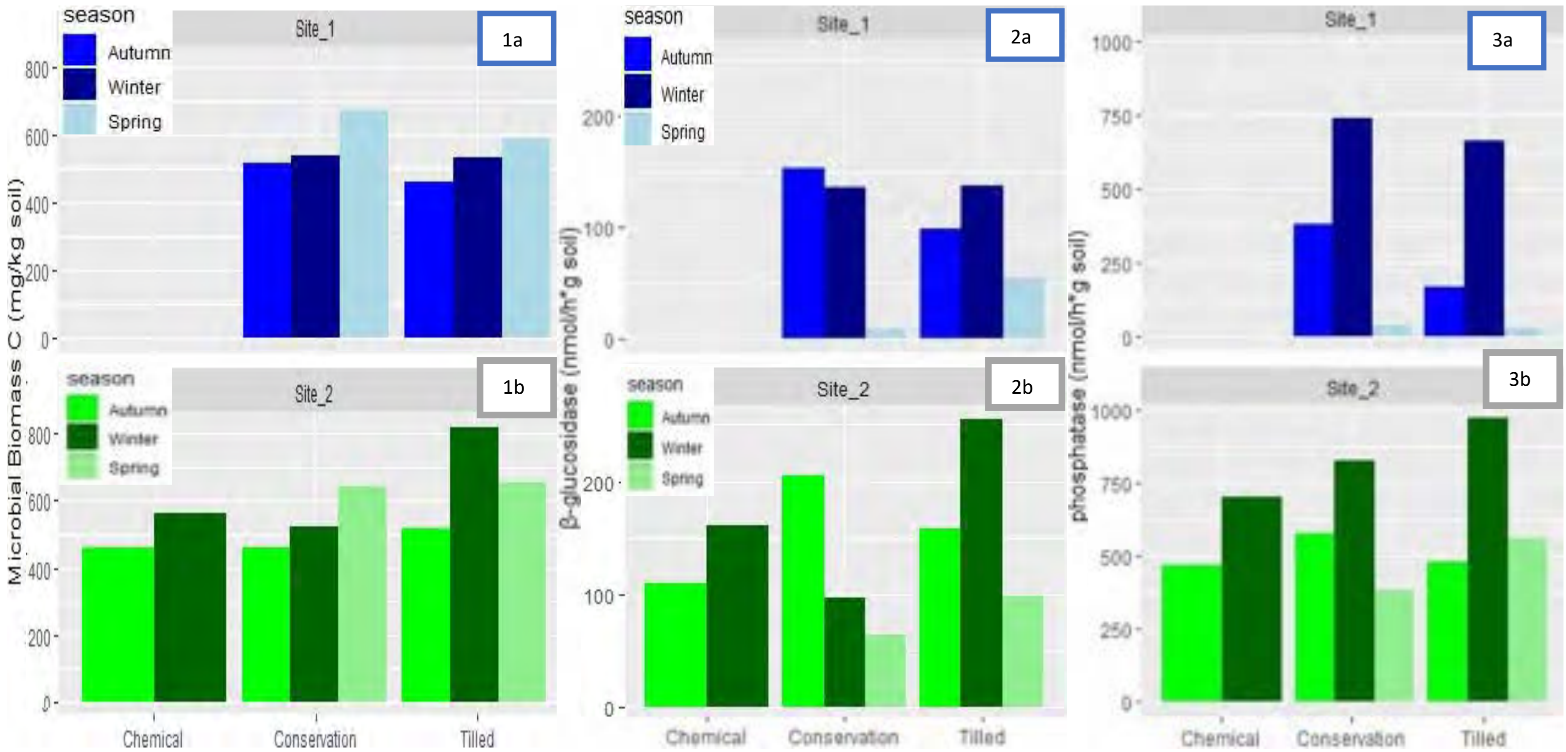

Figure 1) *Soil microbial biomass C for Site 1 (a) and Site 2 (b) for three seasonal samplings, categorized by management practice. 2) β-glucosidase activity for the two sites (2a Site 1, 2b Site 2). 3) phosphatase activity for Site 1 (3a) and Site 2 (3b).*

Discussion

Chemical properties of the sampled soils were assesed using standard methods of analysis. Considering the importance of microbial biomass C (MBC) and enzyme activity (β-glucosidase and phosphatase) on C cycling and carbon use efficiency, we monitored MBC and EA seasonally. Overall, MBC showed similar seasonal patterns across fields and treatments, with the exception of tilled treatment in Site 2, during the winter (Fig 1). The strong seasonal shifts in the Mediterranean basin heavily affect the enzyme activity through factors such as temperature and soil moisture (Zuccarini et al., 2023). The cold and heat stress during winter and summer, respectively, is expected to lower the enzyme activity. In our case study we observed that during the spring sampling, enzyme activity reached its lowest values (Fig 2 & 3), but the causes of this response remain unclear. As for β-glucosidase activity (Fig 2), both conservation and conventional practises showed similar trends across sites, respectively. The conservation treatment showed higher β-glucosidase activity during autumn sampling for both sites, while conventional treatments during winter. In addition, our findings showed that phosphatase activity (Fig. 3) reached its highest during winter. Based on the chemical properties of the sites (Table 1), we can observe that the conservation treatment of Site 1 stimulated SOM accumulation, contrary to Site 2.

Conclution

Understunding the temperature sensitivity of SOM decomposition in semi-arid soils, like in the Mediterranean basin, would help predict their response to climate change (Adekanmbi et al., 2022). Our preliminary findings reveal mechanistic insights on the factors regulating carbon cycling and sequestration in agroecosystems. Specifically, the effects of MBC on carbon sequestration and the contrasting patterns of enzyme activity on carbon cycling between fields and agronomic management practices. Both microbial biomass carbon and enzyme activity seem to be affected by seasonality indipendetly of the management treatments. Additional research is needed to elucidate the factors that are responsible for the observed differences across the fields.

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References:

Adekanmbi, A. A., Dale, L., Shaw, L., and Sizmur, T. Differential temperature sensitivity of intracellular metabolic processes and extracellular soil enzyme activities, Biogeosciences, 20, 2207–2219, https://doi.org/10.5194/bg-20-2207-2023.

Bell, C.W., Fricks, B.E., Rocca, J.D., Steinweg, J.M., McMahon, S.K., Wallenstein, M.D. High-throughput Fluorometric Measurement of Potential Soil Extracellular Enzyme Activities. J. Vis. Exp. (81), e50961, doi:10.3791/50961 (2013).

Karaca A., Cetin S. C., Turgay O. C., Kizilkaya R., 2011, "Soil enzymes as indication of soil quality", G. Shukla and A. Varma (eds.), Soil Enzymology, Soil Biology 22, p119-122, DOI 10.1007/978-3-642-14225-3_7

Pisante M., Stagnari F., Acutis M., Bindi M., Brilli L., Di Stefano V., Carozzi M., 2014, "Conservation Agriculture and climate change", Farooq M., Siddique K. H. M., Conservation agriculture, p579-589.

Zuccarini P., Sardans J., Asensio L., Penuelas J., 2023, Altered activities of extracellular soil enzymes by the interacting global environmental changes, Glob Change Biol. 2023;00:1-25, DOI: 10.1111/gcb.16604.

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