1st International Life Cycle Assessment Symposium

Towards Circular Water and Nutrient Management for Food Production

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Abstract Book

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Foreword

"The Symposium was conceived as a venue to discuss how to effectively evaluate new forms of food production using LCA and whether they hold potential to reduce our impacts on the environment"

Providing access to safe, affordable, local and sustainable food products is now more urgent than ever. Recent extreme weather events such as prolongued droughts and flash floods, along with sociopolitical instability, highlight the fragility of our food systems. Food production mainly relies on scarce natural resources, such as water, mineral fertilizers and soil, especially in highly urbanized areas. While innovative forms of local food production are slowly catching up, several new trends still need to be better discussed and quantified. One of them is the application of circularity principles in the production of food, which are conceived as a way of reducing resource consumption but carry with them new concerns. Such is the case of using reclaimed water or recovering fertilizers from wastewater, which results in benefits and impacts on water, soil and human health. In this sense, life cycle assessment (LCA) is a powerful tool that is helping us to quantify the environmental impacts of food production, but the challenges of new circular practices still need to be integrated.

The Symposium was conceived as a venue to discuss how to effectively evaluate these new forms of food production using LCA and whether they hold potential to reduce our impacts on the environment. Around 60 international participants joined this three-day event at the Campus of the Universitat Autònoma de Barcelona. To do so, the event was structured into themes that feed this LCA debate from different perspectives:

1 Vertical farms

As a novel form of indoor agriculture, vertical farming is becoming increasingly popular to support local food self-sufficiency. However, rising concerns around their actual environmental benefits demand more in-depth analysis. The Symposium brought together new circular approaches applied to vertical farms, from new substrates to renewable energy sources.

2 Circular water management

Circular strategies such as rainwater harvesting or reclaimed water use are alternatives that need more careful exploration in the context of LCA. Examples from rooftop gardens and wastewater treatment plants in the Mediterranean were addressed in the Symposium. From a methodological point of view, a novel water footprint approach was presented.

3 Circular nutrient management

Alternative forms of nutrient recovery and management in urban and rural agriculture are not sufficiently addressed in the LCA literature. A broad sample of biofertilizers and their environmental assessments were covered during the Symposium, from pruning waste to human urine.

4 Direct emissions and impacts

A key challenge in the LCA of food systems is the collection of primary data related to direct emissions to air, water and soils, and their proper translation into impact categories. The Symposium integrated knowledge from LCA modelling and experimental sampling campaigns to identify key challenges and hotspots in this quantification.

5 Innovations for urban agriculture and upscaling potential

To fully grasp the dynamics of new circular practices, a socio-metabolic perspective is needed so that emerging variables and trends are integrated into environmental assessments. For this reason, innovative technologies for local fertilization and greenhouse management were discussed at the Symposium along with stakeholder and urban scale data.

About the organizers

The Symposium was organized by the Sostenipra Research Group of the Institute of Environmental Science and Technology (ICTA-UAB) at the Universitat Autònoma de Barcelona (UAB).

Organizing committee
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The Symposium was a joint effort of different projects that address nutrient and water circularity and food production from different perspectives.

SPORE-MED. Sustainable uPgraded WWTPs for resOurce recovery, water Reuse and hEalth surveillance in the MEDiterranean region

SPORE-MED aims to enhance the environmental, economic and societal sustainability of wastewater treatment plants by developing and upscaling a combined set of innovative water treatment and resource recovery technologies, sensors, online measurement devices, sustainable agricultural practices, and health surveillance protocols.

Project partners:

This project is part of the PRIMA programme supported by the European Union (Agreement 2322)

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FOCUSE. Food production and provisioning through Circular Urban Systems in European Cities

FOCUSE aims to research the development of circular food systems within urban environments across Europe. The project seeks to address an array of complex challenges associated with transitioning to more sustainable, efficient, and resilient urban food production and consumption systems.

Project partners:

This project is funded by the EU's Horizon Europe research initiative, via the EU partnership programme Driving Urban Transitions (DUT). UAB is funded by the Spanish Research Agency (PCI2023-145954-2)

https://www.ivl.se/english/ivl/project/focuse.html

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MOVE4EDU. Modular ventilation system integrated with urban food production in educational buildings

The MOVE4EDU project aims to develop and implement a natural modular ventilation solution that is adaptable, ensures indoor air quality, increases building sustainability, and introduces circular economy principles in the operation of buildings. The central case study are educational centers in Catalonia along with experimentation on urban food production and circular resource management in buildings such as ICTA-ICP.

Project partners:

This project is funded by the Spanish Ministry of Science and Innovation and the Spanish Research Agency (PID2021-126845OB-C21 & MOVE4EDU PID2021-126845OB-C22, MCIN/AEI/10.13039/501100011033/FEDER, EU)

https://www.fertilecity.com/en/move4edu-en/

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A few words from the keynotes

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LCA in food systems research: Reflections and critical examination

Michael Martin

Senior Researcher at IVL Swedish Environmental Research Institute and Professor (Adjunct) of Sustainable Production and Consumption Systems at the Royal Institute of Technology (KTH)

Food systems are increasingly evaluated through the use of life cycle assessment. While originally developed to identify environmental hotspots and guide improvements, LCA is now widely used in food production, retail, and procurement, although its application has shifted. What was once a diagnostic tool is often reduced to single-number footprints, compliance exercises, or use solely for marketing claims. This raises important questions, including, 'Who defines sustainability, how are results framed, and whose interests are served?'

This keynote offers a critical review of how LCA is shaping food system sustainability. Drawing on experience from both academic research and industry collaborations, it examines how assessments have evolved into a kind of currency for standards, labels, and investment strategies. While this has raised the visibility of environmental impacts, it also risks narrowing complex systems into simple metrics, often overlooking the need for openness, balanced perspectives, and a fuller understanding of trade-offs.

The talk argues that LCA should not be treated as a neutral calculator, but understood as a practice shaped by assumptions, choices, and power dynamics. When approached with more reflection and openness, it can move beyond compliance and branding to provide meaningful insights, identifying real opportunities for improvement, highlighting unintended consequences, and supporting more constructive debates about the future of sustainable food systems.

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A few words from the keynotes

What nutrient circularity can contribute to sustainable urban food systems

Anastasia Papangelou

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Urban food systems face a multitude of pressing challenges: limited space for food production and the need for expensive and polluting infrastructure to make up for it; contaminated soils that further constrain the food growing capacity; persistent inequalities in access to nutritious food, and the demand for convenience in fast-paced urban lifestyles that fuels both fast food consumption and food waste generation.

In this context, what role can nutrient circularity play? Is the reuse of secondary nutrients urgent and impactful enough, to warrant our time, energy and public investment?

My short answer is: yes. In this talk I will elaborate on this answer and argue that fostering nature-based nutrient cycling in cities is not only beneficial from an environmental point of view, but also instrumental in driving the transition toward more equitable food systems, and ultimately a more just and inclusive society.

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A few words from the keynotes

New impact categories to drive LCA in decision making: a case study for fishmeal production

Ian Vázquez Rowe

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Life Cycle Assessment has traditionally relied on improvements in life cycle inventory and assessment methods to provide new insights on the environmental profile of production systems, with the aim of expanding the capacity of the methodology to aid in decision making in public and private sectors. Recent advances in computational power have also led to a surge in the initiatives that allow for a broader spectrum of datasets with life cycle inventories, including sectorial (e.g., HESTIA, GFLI…) or national (e.g., PeruLCA, IBICT…) databases. Similarly, this surge can also be seen in the number of assessment methods that are being recurrently updated (e.g., Impact World+, IPCC…) or launched (e.g., GLAM), which share a common trait, the emergence of improved or new impact categories that represent impact pathways that had not previously been developed in life cycle metrics. In this context, impact pathways related to the marine compartment have had a notable evolution in the past few years, as they were traditionally underrepresented in life cycle impact assessment methods. Hence, the objective of this keynote presentation is to illustrate how these new impact categories (e.g., fishing stock removal from the ocean, seabed damage, plastic emissions damage…) have developed and are being applied in LCIA. For this, a case study on Peruvian anchoveta (Engraulis ringens), the largest fishery in the world and the main source of fishmeal for the aquaculture sector worldwide is used as a case study, analyzing the advantages of using the categories, but also discussing their main methodological setbacks.

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Vertical farms

Prospective environmental impacts of vertical farming in Europe: analysis of future technological advancements

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Controlled Environment Agricultural (CEA) systems are steadily expanding across Europe in response to a growing population and the need to address climate change challenges in agriculture. In recent years, various food production technologies have emerged within CEA systems, aiming to reduce the environmental impacts of conventional farming. While greenhouses have been in use for decades, other CEA technologies, such as vertical farms, are still in its infancy, but improved maturity levels are expected to be reached in the future. However, comprehensive assessments of how these systems will evolve and their resulting environmental impacts remain scarce. This research addresses this gap by analyzing the future development of vertical farms across Europe, focusing on increased adoption of circular strategies and improvements in LED system efficiencies among other improvements. Using prospective Life Cycle Assessment (pLCA), this study provides more accurate predictions of future environmental impacts by considering both technological advancements within CEA systems (foreground) and broader socio-economic changes (background). Ultimately, this project aims to contribute to generate actionable insights into the environmental sustainability of CEA and contribute to advancing prospective LCA in agricultural production systems.

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Exploring the potential of circular strategies for improving the environmental performance of a commercial vertical farm

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Vertical Farming (VF), the practice of growing food in vertically stacked layers under artificial LED lights, has largely increased in the recent years. VF has been proposed as a way to increase self-sufficiency and resilience in food systems. However, commercial VF systems typically adopt a linear approach by sourcing inputs elsewhere and disposing the waste produced in a conventional way. The following study evaluates how the adoption of circular strategies can improve the environmental performances of a vertical farm located in Sweden. Life Cycle Assessment (LCA) is used to assess the different circular scenarios for improvement options. The use of brewer's spent grains and spent mushroom substrate were assessed for replacing conventional growing media, while biogas digestate was assessed for replacing fertilizer. The use of organic waste produced by the vertical farm (stems, roots and used growing media) for mushroom production was also assessed. Results indicates that environmental performances improvement can be achieved when circular strategies are adopted. Use of spent mushroom substrate as growing media replacement led to a 14% reduction in global warming potential (GWP), mainly due to the avoidance of employing peat-based media. Replacement of synthetic fertilizer with biogas digestate resulted in a 28% reduction in freshwater eutrophication. Moreover, mushroom production with organic waste improved resource efficiency with a 40% reduction in total waste output. The study suggests that adoption of circular strategies have the potential to improve environmental performances of the vertical farm while promoting a more resilient food system.

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Sustainability of Vertical Farming in the Mediterranean: A Comparative LCA of Natural gas and Renewable Energy Sources

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The implementation of vertical faming in the mediterranean context, while still in its infancy, has been widely considered as a potential solution for current limiting conditions on open field and low-tech greenhouse production such as cooling needs and water scarcity. While the use of some resources has been widely regarded to be reduced in vertical farming practices, the higher installation cost and energy use still imply major contributors to the production system also translating into their environmental footprint. The present work presents the case of a vertical farm dedicated to the production of lettuce for the ready-to-eat market, with a diversified use of energy sourcing. The farm proposes the use of biomethane for the energy and heat production with a co-generator combustion to supply the current use of natural gas. The methodology used for the comparison of biomethane, and natural gas emission is attributional LCA with the addition of alternative scenarios of feed to produce the origin biofuel. Additionally, the study evaluates the integration of renewable energy sources more readily available in Italy, analyzing their potential to mitigate the environmental impact of vertical farming. The results provide insights into the role of energy sourcing in shaping the sustainability of vertical farming systems. Furthermore, the study explores the application of allocation processes for bio-based fuel production from anaerobic digestion, incorporating RED II-compliant calculations into the attributional LCA framework to ensure compatibility with certification standards.

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Reuse of coconut fiber for microgreens cultivation in a vertical farming facility: evaluating growth and light use efficiency for kale and mustard microgreens

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Vertical farms as food production systems may reduce their environmental impact by integrating a circular economy approach in the management of growing media. However, few studies have quantified plant performances with reused substrates in indoor agriculture, especially in vertical farm facilities, even if reusing growing media may reduce the overall resource use of indoor agriculture. The goal of this study was to compare newly sourced and reused coconut fiber growing media by inspecting the growth and light use efficiency of hydroponically grown microgreens, namely kale (*Brassica oleracea* cv. Ciro) and mustard (*Brassica juncea* cv. Senape Pistol), grown on both substrates under the same lighting and environmental conditions. The plants were grown under two different light intensities, both with a red and blue spectrum with a ratio of 1 (RB1-200 with a light intensity of 200 μmol m^{-2} s^{-1} and RB1-250 at 250 μmol m^{-2} s^{-1}). The two lighting treatments were performed on both newly sourced and reused substrates for each microgreen species. Morphological and physiological parameters were measured to evaluate plants' performance. This research investigated the potential of the reused substrate and its related environmental benefits as a part of the circular economy strategy for vertical farming, contributing to understanding waste circularity management and resource use reduction to optimize the environmental impact of indoor agriculture.

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Circular water management

Circular water management

Life Cycle Assessment of Circular Water Management: evaluating the use of treated wastewater and composted sludge for sustainable agriculture in semi-arid regions

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This study investigates the impact of using treated wastewater for irrigation and composted sludge as a soil amendment in the semi-arid region of Rehamna, Morocco. The work presented here is conducted as part of the SPORE-MED project which aims to generate knowledge on reducing resource use and improving sustainability in food production. In this study we are assessing the effects of using treated wastewater and composted sludge on sandy and loamy clay soils under two test crops (Sorghum and Cowpea) subjected to two irrigation systems (surface drip and subirrigation). Specfifically, we will conduct field trials to evaluate crop growth, yield and nutrient uptake as well as soil microbial diversity parameters. In addition, we will set-up a lysimeter-based experiment to conduct in-depth assessments on microbiological dyanmics, soil health, nutrient recovery, and water use efficiency. Generated data will be used to conduct a Life Cycle Assessment (LCA) that quantifies the environmental effects of compost and wastewater reuse. The LCA framework will primarily focus on water and nutrient flows. By providing a model for circular water management in semi-arid areas, the study will support the broader social goals of thriving under low rainfall and resource-constrained conditions.

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Environmental benefits of energy recovery in wastewater treatment plants

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Wastewater treatment plants (WWTPs) play a crucial role in ensuring the availability of water, a key and increasingly scarce resource in the Mediterranean region. These facilities are essential for enhancing climate resilience in local communities, yet they are also characterized by high energy demands, accounting for up to 4% of a country's total electricity consumption. Furthermore, WWTPs generate substantial quantities of waste, particularly sewage sludge, which requires appropriate treatment and disposal. The SPORE-MED project aims to assess the environmental impacts associated with conventional wastewater treatment processes and to evaluate whether technical improvements can lead to a reduction in these impacts. In addition, the project investigates whether the recovery and valorization of certain waste streams can further offset the environmental burdens. To achieve these objectives, a life cycle assessment (LCA) will be conducted on existing WWTPs, and their environmental performance will be compared against a scenario in which these same facilities operate using the PROGRAMOX technology. Operational data for this proposed plant configuration have been obtained theoretically, based on information derived from a pilot-scale PROGRAMOX plant located in La Garriga. Preliminary results suggest that the new configuration could lead to a reduction in the plant's overall electricity consumption and an increase in biogas production for self-consumption, thereby decreasing the environmental impacts associated with the treatment process.

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Water footprint assessment: a focus on Italy's wine industry

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Along with its economic importance, the Italian wine industry is associated with relevant environmental impacts. Most notably, such impacts include over-exploitation of water resources and decreasing water quality. As such, water footprint evaluation is rapidly becoming a crucial objective for achieving a higher level of sustainability of agricultural practices while maintaining the quality of products. Among the available water accounting methods, Life Cycle Assessment (LCA) is a powerful tool that allows to both measure water uses along agri-food products production chains and to measures potential environmental impacts associated with water consumption. A case study from the Italian agricultural sector is presented, a large scale conventional wine company (over 980 ha) with a yearly production exceeding 10,000,000 bottles. In this case study, two different sets of measures for analyzing the flow of water resources and optimizing water uses within a life cycle framework were developed and applied: i) a novel methodology based on econometric modelling to estimate water requirements of grapevine, and ii) the application of a custom water recycling system at the facility that allows to reduce water consumption during the cellar and packaging phases. Results show that both measures allow to effectively keep track of the consumption of freshwater resources and to optimize their use within an agri-food setting.

This study was carried out within the AGRITECH National Research Center and received funding from the European Union Next-Generation EU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) – MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.4 – D.D. 1032 17/06/2022, CN00000022). This manuscript reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.

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Rainwater Harvesting and Smart Irrigation in Urban Agriculture: A Case Study from Barcelona

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Urban agriculture (UA) is a key strategy for building more sustainable cities, promoting circular economy practices, enhancing biodiversity, and creating green spaces. Despite its multiple benefits, efficient water management remains a major challenge—especially in small-scale urban settings and for users lacking advanced technical knowledge. This study presents a case study of an urban rooftop garden located in Barcelona, managed by the start-up Tectum Garden, where rainwater harvesting has been integrated into the building's infrastructure. The objective is to evaluate the effectiveness of rainwater use in reducing the environmental impact associated with irrigation for food production. The study includes production data from the past year, focusing on the volume of rainwater used, the resulting reduction in potable water consumption, and the overall environmental impact assessed through Life Cycle Assessment (LCA). The analysis also considers the use of additional water-saving technologies to optimize irrigation in urban horticulture. The results aim to demonstrate the relevance and benefits of implementing rainwater harvesting systems and smart water use strategies in productive green areas across Mediterranean cities. The findings support the case for integrating circular water management into urban agriculture to reduce pressure on municipal water supplies and improve urban sustainability.

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Circular nutrient management

Greenhood project – Dual LCA Approaches on a nutrient recovery framework

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The disruption of nitrogen (N) and phosphorus (P) cycles, driven largely by agricultural fertilizers and livestock manure, poses significant environmental challenges. Addressing this issue, the GREENHOOD project seeks to reduce nutrient emissions and rebalance regional nutrient flows by targeting critical hotspots and engaging local stakeholders. The GREENHOOD project will implement regional pilots across five countries focusing on sectors and regions with imbalanced nutrient flows. These demonstrators will prioritize the development of sustainable value chains for Bio-Based Fertilizers (BBFs), which repurpose recovered nutrients into viable alternatives to synthetic fertilizers. Central to its strategy are nutrient budgeting methodologies and innovative technologies designed to close resource loops, aligned with EU's the INMAP (Integrated Nutrient Management Action Plan) aims to halve nutrient losses by 2030, emphasizing the urgent need to transform agricultural practices. A life cycle assessment (LCA) with two approaches: attributional and consequential, will evaluate the environmental impacts of transitioning to biofertilizers. A simplified attributional LCA will assess ~18 solutions to quantify the potential impacts. This information will contribute to the consequential LCA, which will analyse the four pilot sites globally, in order to have a systemic view, such as reduced reliance on mineral fertilisers and avoided environmental burdens. Together, these frameworks will guide sustainable decision-making. In that sense, attributional LCA will identify high-performing solutions, while consequential LCA will reveal broader benefits of scaling biofertilizers and disruptive market fluctuances. This integrated approach will allow to ensure circular nutrient strategies are ecologically viable and scalable, reducing the waste and optimizing the resources for future generations.

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Applying recovered nutrients and pruning waste to enrich and regenerate agricultural soils in urban agriculture: Life cycle environmental benefits and trade-offs

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Peri-urban agriculture (UA) and nutrient circularity are promoted to increase food self-sufficiency and resource efficiency while reducing environmental impacts associated with mineral fertilizer use and waste management. However, while nutrient-rich waste is generated in cities, nutrient circularity remains far from significantly substituting mineral fertilizers in UA. An obstacle is the carbon-poor state of soil, as adding nutrients in this state is counterproductive for nutrient cycling. A solution within cities is enrichment and regeneration of agricultural soil through carbon-rich residues, improving nutrient cycling before nutrient recovery. We study if and how cities can benefit from regenerating and fertilizing UA soil through carbon recovered from pruning residues jointly with various circular nutrient strategies (CNS). The Metropolitan Area of Barcelona (AMB) serves as the area of study, for which experimental data of spinach and sweet potato cultivated with different treatments was used as inventory data (including CO_2, CH_4, NH_3, and N_2O emissions measured on-site). Geographically explicit material flow analysis (MFA) and life cycle assessment (LCA) were applied to determine the upscaled potential of pruning residues to regenerate UA soils in the AMB, the trade-offs between different treatment fates of pruning residues, and the benefits of replacing mineral fertilizer through CNS. Environmental impact assessment results are proceeding, including the integration of soil organic carbon as an indicator of soil regeneration. This study highlights the novelty of resolving the soil-related obstacles of sustainable UA in cities through carbon and nutrient circularity by understanding the entire cycle: from waste to food.

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Is urine recovery the new best practice for reducing the environmental impacts of local food production?

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Finding new fertilization sources is essential to reducing the environmental impacts of agricultural systems. The Haber-Bosch process is currently supplying most of the synthetic nitrogen fertilizers needed for agriculture, which demand large amounts of energy that are typically sourced from fossil fuels. Nutrient recovery is thus a much-needed solution, but it must not compromise the environmental sustainability of food systems. In this study, we present the life cycle assessment (LCA) of a novel concept for urban farms that is based on the recovery of human urine from buildings and its transformation into viable nitrogen fertilizer in a bioreactor. Through the BINAFET project, a lab-scale system was implemented at the ICTA-ICP building. The study suggests that recovering 1 m^3 of urine could be used to produce 2.4 tons of tomatoes in open-field urban farms. Compared with conventional wastewater treatment, this solution generates 2.8 times less impact on eutrophication by avoiding the release of nitrogen into water bodies. Nevertheless, its lab-scale set-up does not yet balance out the impacts of the system on global warming (59.1 kg CO_2-eq/m^3) with respect to the synthetic fertilizers displaced from the market (40 kg CO_2-eq/m^3). Our study suggests that the volume of recovered urine is critical in making this technology viable with respect to synthetic fertilizers, and is thus an interesting option for large facilities, such as schools or compact neighborhoods. Contaminant tests confirmed that pharmaceutical compounds are not present in crops grown with this fertilizer, which can facilitate this upscaling of the system.

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Direct emissions and impacts

LCA and inclusion of soil health related Ecosystem Services of Agricultural Organizations

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Agricultural organizations are complex, multifunctional systems that generate food and waste, and depending on how activities are carried out, may impact or benefit soil health and related ecosystem services (ES). Intensive management and over-reliance on external inputs can result in significant environmental burdens. While Life Cycle Assessment (LCA) is a valuable tool for evaluating the environmental impacts of agriculture, there is no consensus on how to integrate soil health-related ES into this assessment process. This study develops and applies a conceptual framework that allows to conduct an LCA both at Organizational and Product level that includes soil health ES in an Italian case study, focusing on an organization implementing strategies to enhance environmental performance, reduce water use, and improve soil health. Key steps include: i) structuring the Life Cycle Inventory (LCI) to account for input-output circularity, and assess impacts like Carbon and Water Footprint (CF and WF), while incorporating allocation strategies for a product-level evaluation; ii) analysis of preliminary results of water harvesting techniques (e.g., Small Agricultural Reservoirs:SmAR) to reduce blue water inputs, and of certain farming practices to improve soil quality and to reduce irrigation needs. Future activities will focus on assessing water and carbon LCI under climate change scenarios, comparing conventional and agroecological practices with and without SmAR. On one hand, the reduction in WF will be evaluated, while on the other, potential carbon sequestration, increased soil ration capacity and reduced soil erosion will be assessed through soil organic carbon as a soil health indicator.

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Mitigating N_2O Emissions with Urban Pruning Waste: A Field Study on Spinach Fertilization

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Agricultural soils face numerous stresses from frequent mineral fertilization, tillage, and organic carbon loss. A potential solution is incorporating urban pruning waste to increase soil organic carbon to enhance water and nutrient retention, improve the quality of the crops and reduce the impacts of flooding and droughts. Furthermore, the unstable carbon from pruning residues binds more easily to the nitrogen in the soil resulting in potentially lower NH_3 and N_2O emissions compared to conventional fertilization. According to IPCC guidelines, conventional fertilization treatments emit 1% of the nitrogen applied in the form of N_2O. We measured the N_2O emissions of a spinach cycle by using static chamber and analysed the samples by gas chromatography. The experiment was set in El Prat de Llobregat (Barcelona), between February and April. Four fertilization treatments with different nitrogen doses were adopted: A) Mineral fertilizer (73.3 kg N ha^{-1}); B) Struvite and organic nitrogen (73.6 kg N ha^{-1}); C) Compost (352.5 kg N ha^{-1}); D) Pruning residues (2330.3 kg N ha^{-1}). The highest EF was observed in B (0.33%), likely due to the high amount of ammonium applied with struvite, followed by A (0.31%), C (0.008%), and D (0.002%). Our results show how the source, more than the quantity, of nitrogen is a key component for N_2O emissions and highlights the importance of field measurements, rather than relying only on the emission factor suggested by the IPCC for environmental assessments.

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Direct emissions and impacts

Monitoring BVOCs emission from urban food systems: the case of integrated rooftop greenhouse and vertical farm

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Urban Agriculture (UA) can be implemented in systems such as integrated Rooftop Greenhouses (iRTGs) and Vertical Farms (VFs), although these setups face several challenges, particularly related to air quality and regulatory compliance. Volatile Organic Compounds (VOCs) contribute to indoor air pollution and may pose health risks. With the expansion of UA, biogenic VOCs (BVOCs) are expected to increase, though their impact remains difficult to predict due to multiple related factors such as temperature, relative humidity, and light radiation. Over the past four years, we monitored BVOC emissions from commonly grown crops—green bean, tomato, and basil. Measurements were conducted in iRTG or VF systems, considering emission levels, influencing factors, safety thresholds, and potential health risks. In both environments, detected emissions were within parts-per-billion (ppb) levels and exhibited chemically different emission profiles. In the iRTG, emission peaks were detected early in plant development and decreased over the cycle, as observed in green bean and basil plant. Environmental conditions significantly influenced emission trends. For example, in the iRTG, slight variations in CO_2 concentration triggered a stress response in tomato plant, while the application of urine-enriched fertilizer double basil emissions. Similarly, in VF, different blue and red-light ratios induced distinct basil emission profiles at specific growth stages. Safety was evaluated against official indoor exposure limits (EU-LCIs). Despite the limitation of reference LCI values, overall BVOCs emissions were far below harmful thresholds. Occasional emission peaks were deemed non-threatening due to their shortage and high dispersiveness. Furthermore, this research provided detailed BVOC emission data for LCA inventories build-up and improve the accuracy of environmental assessments.

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Environmental assessment of groundwater remediation from a biodiversity approach

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Groundwater sources represent one of the world's most vital freshwater reserves. However, these resources are increasingly threatened by pollution, making their preservation and restoration critical for sustaining ecological balance and enhancing human resilience to climate change and variability. Protecting the integrity of groundwater systems is thus essential for both environmental sustainability and human well-being. In this context, BIOSYSMO is an ongoing European project focused on developing nature-based technologies for soil and groundwater remediation. The project investigates several innovative approaches, including bioelectrochemical systems (BES), BES combined with phytoremediation, and bioaugmentation-biostimulation strategies. Additionally, conventional physico-chemical treatments, such as photo-Fenton processes and adsorption using commercial zeolites are also considered for groundwater purification. All proposed technologies have been evaluated using Life Cycle Assessment (LCA), following ISO standards. While human interventions in ecosystems often compromise biodiversity and ecosystem services, current Life Cycle Impact Assessment (LCIA) methods typically lack granularity in assessing such impacts. Emerging methodologies such as Ecological Scarcity and IMPACT World+ offer more detailed evaluations of biodiversity and ecosystem service implications. In contrast, conventional LCIA approaches like ReCiPe Midpoint focus primarily on broader categories such as water use, climate change, and resource depletion. Both conventional and biodiversity-oriented LCIA methods have been applied to the BIOSYSMO scenarios. Preliminary results indicate a correlation between key contributors across both conventional and biodiversity LCIA approaches. BES-related environmental impacts are highly sensitive to system scale. For physico-chemical options, zeolite synthesis has emerged as the dominant contributor to environmental burden in adsorption processes. In the case of Pump and Treat (P&T) systems with activated carbon desorption, regeneration of the activated carbon is essential for ensuring the scalability and feasibility of the treatment.

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Preliminary Results on Nitrogen Emissions in Hydroponic Lettuce Production with Urine-Derived and Mineral Fertilization

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Nitrous oxide (N_2O) is a major greenhouse gas (GHG) associated with agricultural and horticultural food production, with hydroponic greenhouse systems having high emission potential (273 times that of CO_2 for a 100-year timescale) due to intensive nitrogen fertilization. However, knowledge on fertilizer-derived GHG emissions from greenhouse vegetable cultivation remains limited. Most studies continue to use the general 1% emission factor for agricultural soils proposed by the Intergovernmental Panel on Climate Change (IPCC) since 2006. Nutrient recovery from waste streams can reduce agriculture's environmental impact while enhancing nitrogen efficiency. At ICTA-UAB, source separated human urine is processed by hydrolyzing urea and nitrifying ammonium to nitrate for its use as liquid fertilizer in hydroponic cultivation. This study assesses the arising N_2O emissions from synthetic nitrogen fertilizers compared to the use of nitrate from treated human urine as an alternative nitrogen source in hydroponic lettuce cultivation. Several experiments were conducted in the rooftop greenhouse using two types of closed chambers, for two consecutive trials. The chambers have a capacity for nine (0.146 m^3) and ten (0.455 m^3) lettuce plants (Lactuca sativa) grown in perlite over a 30-day cycle. Chambers were equipped with sensors for temperature, radiation, and humidity. N_2O emissions were measured through gas chromatography, performed with an HP-PLOT-Q column, a 95% Ar / 5% CH_4 makeup gas, and an electron capture detector (ECD). Findings will improve understanding of N_2O emissions in hydroponic systems and the role of alternative nitrogen sources in reducing GHG emissions. Data will support the inclusion of hydroponic horticultural products in life cycle inventories.

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Innovations for urban agriculture and upscaling potential

CONFETI: Fertilizing the future with a self-powered, sustainable solution based on CO_2 capture and N-compounds

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The global fertilizer market, valued at nearly $400 billion, is projected to reach around $550 billion by 2030, growing at an annual rate of 6%. In Europe, the market is expected to hit $72 billion within the next six years, driven by demographic expansion and increasing food demand. Nitrogen-based fertilizers, such as ammonia and urea, account for 70% of fertilizers used in agriculture. However, their production via the Haber Bosch process is energy-intensive and polluting, contributing over 1% of global greenhouse gas emissions and 15% of the chemical industry's CO_2 emissions. Addressing these environmental issues is crucial for developing sustainable and precision agriculture practices. The CONFETI project (Green valorisation of CO_2 and Nitrogen compounds for making FErTIlizers) proposes a sustainable, cost-effective approach to fertilizer production. It aims to reduce reliance on fossil fuels and mitigate environmental impacts by developing a self-sustaining system that uses photo- and electrochemical technologies to capture CO_2 and nitrogen compounds from air, flue gas, or residual water, converting them into urea or ammonia in situ using renewable energy. This system promotes a circular economy and sustainable agriculture, addressing global challenges like rising CO_2 emissions, energy demand, food scarcity, and nitrogen pollution. CONFETI's modular device includes an electrochemical reactor, a microbial fuel cell, and a photochemical reactor, enabling autonomous fertilizer production without storage or transport needs. The project involves a multidisciplinary team from various international institutions, including the Autonomous University of Barcelona and partners from Spain, Belgium, Italy, France, and the USA. In this presentation, we will showcase the key advancements of the CONFETI project and its significant progress in developing sustainable and cost-effective fertilizer production methods. We will also highlight how CONFETI is contributing to a greener and more efficient agricultural future.

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Airgilab Living-Lab: Integrated Ventilation for Circular Resource Management in Building-Integrated Agriculture

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Urban agriculture, encompassing vertical farms and building-integrated agriculture, presents a promising avenue for circular food production within urban environments. However, optimizing resource use and minimizing environmental impacts is crucial for its sustainability. This study investigates the integration of a novel, natural modular ventilation system within building-integrated greenhouses to enhance both indoor air quality (IAQ) and food production (FP), contributing to a circular economy. The Move4Edu project introduces a ventilation system designed to address the challenge of insufficient ventilation in educational buildings, prevalent in regions like Spain, where traditional mechanical ventilation is often considered costly. This system not only improves IAQ by managing CO_2 concentration but also leverages human-generated CO_2 to boost crop yield within building-integrated greenhouses. This synergy between building ventilation and UA creates a circular loop, reducing energy demand and enhancing food production. This research presents the design, deployment, and preliminary operational results of this ventilation system, implemented in the Airgilab living lab at the UPC building (TR5-ESEIAAT, Terrassa) in the framework of the Move4Edu project. This living lab aims to demonstrate the potential of this system to optimize building energy consumption while fostering circular urban agriculture practices, contributing to zero-carbon emission goals. This innovative approach offers a scalable model for enhancing sustainability in buildings and cities, particularly within educational settings.

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The potential for urban circular food systems in Stockholm County

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Cities face increasing food security challenges and environmental pressures, circular approaches to urban food production offers a pathway to enhance a city's resilience and sustainability. The study aims to map existing urban food production systems, assess their material flows, and co-develop circular models that integrate urban farming with residual resource streams. The study employs a multi-method approach to comprehend Stockholm's urban food landscape. Firstly, it identifies and classifies urban farming initiatives to document production types, technologies, and market channels. Secondly, a material flow analysis is conducted to track food system inputs and outputs, including urban waste streams potentials for circular integration. Finally, an assessment of urban resource exchanges helps explore waste valorisation for improving the resource and energy efficiency of food production in urban farms. The preliminary findings reveal a diverse landscape of urban food production in Stockholm. However, these systems remain largely linear, with limited reuse of urban residuals. Nevertheless, significant opportunities for utilizing organic waste as fertilizer input, redirecting heat from vertical farms to buildings, and re-purposing underutilized urban spaces for food production. Challenges include regulatory barriers, economic viability, and infrastructural constraints. The study concludes that transitioning to a circular urban food system in cities requires systematic changes in policy, infrastructure, and governance. Enhancing resource synergies, integrating circular food production into urban planning, and fostering collaboration between key actors are essential to unlocking urban agriculture's potential as a sustainable and resilient food provisioning strategy.

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Manifesting Carbon and Nutrient Circularity: A Stakeholder-Informed Perspective on Regenerative Urban-Agricultural Systems

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Urban nutrient and carbon flows hold significant potential to build resilient food systems and advance soil regeneration. Applying recovered urban organic matter to soils enhances soil carbon sequestration and aligns with the Milan Urban Food Policy Pact and EU requirements for organic-waste recovery by 2030. Implementing municipal circular systems is challenging due to institutional and social dynamics. The NUTRISOIL project addresses this challenge through three multi-stakeholder workshops at metropolitan and international scales, engaging actors from urban communities and the waste and agricultural sectors. Using the Three Horizons methodology and grounded theory, the study identified core priorities including valorisation of waste for agriculture, circular economy education, incentives, access to infrastructure and machinery, place base regulation, and policy integration across sectors. Climate action priorities often neglect nutrient circularity, indicating an undervaluation of soil health within climate strategies. By incorporating stakeholder perspectives into life-cycle assessment (LCA) frameworks, the study demonstrates how qualitative systems thinking can inform quantitative environmental impact analysis. Achieving urban nutrient circularity requires both technological solutions and inclusive, participatory processes that navigate policy and social dimensions.

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Exploring Circular Economy pathways in Agrivoltaic Systems for Sustainable water and nutrient management

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TAgrivoltaic systems (AVS), which combine farming and solar energy production on the same land, are becoming a promising approach to improve sustainability in agriculture. This research looks at how AVS can support circular economy (CE) goals, especially in managing land, water, and nutrients more efficiently. We conducted a systematic literature review, focusing on studies related to AVS and CE up to early 2025. Results show that AVS help optimize land use, reduce water evaporation thanks to panel shading, and improve soil moisture retention up to 15% in some cases. The shading effect also keeps soil temperatures lower and stable reaching 9°C cooler in some setups, helping crops grow better and improving nutrient uptake efficiency. This can create a better microclimate for certain shade-tolerant crops like leafy greens, cherry tomatoes, berries, and chiltepin peppers. Some researchers from the United States of America are currently exploring the possibility of producing nitrogen fertilizers on-site, which adds value to nutrient management. Other benefits of AVS include soil quality, erosion reduction. In this study, key indicators to measure the effectiveness and sustainability of AVS are explored as well. An example of such indicators is the Water Use Efficiency (WUE) indicator, which measures biomass yield per unit of water used. This study is developed with the support of the SYMBIOSYST project and SENACYT Panama. The findings aim to contribute to current discussions on how AVS can support more circular and sustainable food production systems, especially in rural and peri-urban areas.

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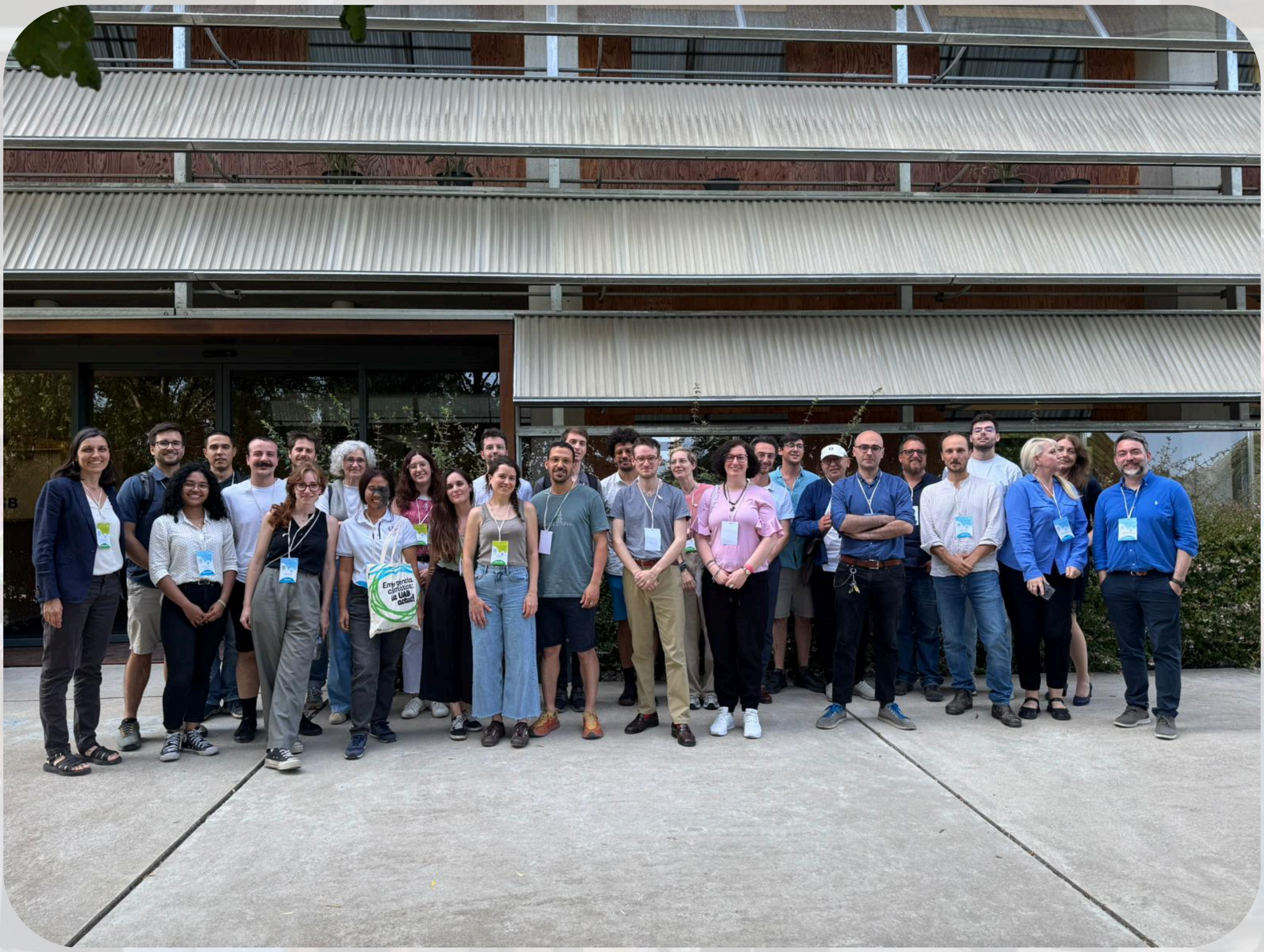

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