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Preface

Various software solutions are employed for conducting Life Cycle Assessments (LCAs). GreenDelta has been at the forefront of this field since 2006, developing the open-source software openLCA, which is highly suitable for LCA studies. Over the years, openLCA has gained global recognition as the most extensively used LCA software. It provides the broadest selection of databases for LCA software, boasting over 300,000 unique datasets. These databases encompass both environmental and socio-economic aspects, enabling reliable computations for Sustainability and Life Cycle Assessment.

In recent years, openLCA has seen significant advancements, not only as a standalone tool but also as a solution integrated with other sustainability tools and add-ons. Complementary tools, such as the LCA Collaboration Server, have facilitated cooperation among LCA practitioners and have also enabled the creation and publication of additional databases. Furthermore, due to its low entry barrier and the availability of resources, openLCA has been widely adopted for LCA studies, projects, and research worldwide.

After the sold-out success of the first openLCA conference, GreenDelta now gears up for the second edition of the openLCA conference. This document encapsulates the proceedings of the second openLCA conference, to be held in Berlin, Germany, on the 10th and 11th of April, 2025. openLCA.conf serves as a networking and exchange platform for openLCA users and enthusiasts. The conference emphasizes the participants' engagement with the software and sheds light on the latest advancements.

The following topics will be discussed at the conference:

- *LCA for Policy and infrastructure*
- *Social LCA*
- *Environmental Product Declarations*
- *Circular Economy*
- *openLCA tools and integrations*
- *Broader Sustainability Assessments*
- *Advancing LCA databases and LCIA*
- *LCA in Food and Agriculture*
- *Alternative Materials*
- *Renewable Fuels and Energy Systems*
- *Advancing LCI*

All abstracts presented in this document were peer reviewed by experienced LCA professionals.

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1. LCA for policy and infrastructure

1.1. Comparing the life cycle assessment of the end-of-life phase of a semi-detached house in the UK and Saudi Arabia

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The significant quantity of demolition waste generated by the construction industry presents environmental challenges that require effective waste management techniques. This study conducted an LCA of the end-of-life phase for two typical semi-detached houses in the UK and Saudi Arabia using OpenLCA software, aiming to compare waste management practices between the regions. The findings reveal that the waste treatment stage contributes the most to environmental impacts, while the house demolition stage has the least impact. For Global Warming Potential (GWP), the house in the UK emits a total of -9,028.1 kg CO2 eq, while in Saudi Arabia it emits 28,353 kg CO2 eq. The differences are attributed to the varying construction materials and the larger size of the Saudi houses, which is three times the size of the UK house. In terms of the end-of-life scenario, recycling contributions across all impact categories highlight its advantage over landfilling and suggest that waste management practices need improvement. The environmental benefits from recycled materials differ by material type. For example, in Saudi Arabia, steel, despite making up only 2.14% of the waste stream, contributes to a 73% reduction in CO2 emissions. Similarly, in the UK, ceramic tiles account for 79% reduction in carbon emissions. Concrete, however, shows minimal CO2 reduction (1-2%), although it represents the largest portion of total waste in both cases (around 80%). The study also assessed waste material contributions across various impact categories, confirming the dominance of materials like ceramic, timber, and steel in overall environmental performance. The key findings are as follows: • Comparing traditional and hypothetical scenarios in Saudi Arabia highlights the need for comprehensive construction and demolition waste (C&DW) management plans to reduce waste. • Recycling metals should be prioritised due to their significant environmental benefits across impact categories. • Reducing transportation impacts, particularly in the end-of-life stage, can be achieved by minimising transport distances and adopting electric heavy trucks. Future research should focus on waste management for typical residential structures in diverse contexts. Data collected directly from demolition contractors will enhance the applicability of the findings, providing more realistic outcomes.

1.2. Life Cycle Environmental Impacts of Urban Water Systems in China

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Urban water systems in China are facing multiple challenges, including rapid urbanisation, climate change and infrastructure ageing. It is crucial to evaluate their environmental performance from a holistic perspective in planning and management processes. To the best of our knowledge, there is a *lack of nationwide life cycle assessment (LCA) studies on urban water systems that cover all system stages. Therefore, this study aims to present a comprehensive and nationwide LCA analysis that pinpoints the environmental hotspots and their major sources across China. This study was conducted based on water utility databases at the province level, covering water abstraction and treatment, waterwork sludge treatment, water distribution, sewage collection, stormwater drainage, wastewater treatment and sewage sludge treatment. Nine environmental impact categories including fossil resource scarcity, freshwater ecotoxicity, freshwater eutrophication, global warming potential, human carcinogenic toxicity, human non-carcinogenic toxicity, stratospheric ozone depletion, terrestrial ecotoxicity, and terrestrial acidification were calculated and analysed. The results reveal the inequity of environmental impacts across provinces, with overall impacts geographically higher in the east and south, lower in the west and north. However, at the functional unit level, the impacts in the northern and northeastern provinces are higher than other regions. Most environmental categories are dominated by multiple water system stages. The analyses of underlying drivers found that purchased electricity is the primary source of several environmental impacts. This study provides a holistic understanding of the environmental performance of China's urban water systems, offers some insights for comprehensive decision-making support on sustainable water system management, and can also serve as a benchmark for future scenario analysis to explore options for reducing environmental impact.*

1.3. Inventory construction and life cycle impact assessment to the Brazilian transition in iron ore feed for blast furnace

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The iron ore feed for pig iron blast furnaces is undergoing a transition from lump ore to sinter ore and pellet ore because the exhaustion of Brazilian mines with concentrated ore, expected to run out until 2030. This transition will require greater energy consumption and other inputs since sinter ore and pellet ore require more complex beneficiation.

An important feature in Brazil is the charcoal use as energy and reductor source. This entry eliminates the coal consumption and reduces the natural gas consumption by up to half. Furthermore, the logistics matrix is mostly freight lorry based and the electrical supply is based on hydroelectric plants. Even so, the Ecoinvent database still does not present a particular impact inventory for Brazil related to the production of sinter and pellet ores. In fact, there is a shortage of scientific papers and reports from local industries on these processes. Therefore, this work prepared Brazilian inventories based on international ones from reference countries, such as China and Europe, and mainly based on Brazilian inventories produced by government agencies. These ones present rich details of the process, but it make clear that the information presented was collected from just under 50% of national industries.

After preparing the inventories, the life cycle impact assessment was carried out using the ReCiPe hierachical midpoint method for delivering one tonne of sinter ore or pellet ore. As both have similar raw iron content, iron delivery will be the same. It was employed an attributional approach based on a cradle-to-gate analysis. The charcoal consumption for the pellet ore production is around four times

lower that the sinter ore, due to it being more energy intensive. Because of this, categories related to land use, such as "Agricultural Land Occupation", "Natural Land Transformation" and "Urban Land Occupation" presented better results for the pellets production. For the same reason, iron pellet production also had a lower impact in the "GWP100" and "Human Toxicity" categories. On the other hand, the categories "Fossil Depletion", "Freshwater: Ecotoxicity and Eutrophication", "Marine: Ecotoxicity and Eutrophication", "Metal Depletion", "Particulate Matter Formation" and "Ozone Depletion" had a lower impact on sinter production due to a lower fluxes consumption compared for pellet. Another important conclusion is that fossils consumption from both processes is directly related to natural gas, but indirectly to diesel used in supply chain processes as machinery fuel.

Keywords: LCI construction, data gathering, pellet ore, sinter ore, ReCiPe.

1.4. Implementation potential of LCA for discrete manufacturing companies

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The assessment of the environmental performance in manufacturing companies is more than the fulfillment of reporting obligations. Rather, companies can differentiate themselves through life cycle assessments (LCA) in the worldwide competition: If carried out in a trustworthy way, LCA results not only support environmental product claims for customers but also work as an anchor point for a structured company system and resource-efficient processes, in which optimizations are implemented across departments, covering from production over quality and supplier management up to the strategic management, as well as across life cycle phases.

However, currently the implementation of LCA is seen as a necessary burden rather than an opportunity for the company. This is mainly due to the necessary time and resource efforts to gather data, the uncertainty about the "quality of data", and the missing expert knowledge in many smaller and medium sized companies (SMA) regarding both data acquisition and LCA methodology.

This paper explores opportunities for manufacturing companies using LCA to enhance their system from a production technology perspective by systematically evaluating implementation scenarios and their cost-benefit-potential. Firstly, the current applications and involved departments are explored. Secondly, future possibilities of using LCA for manufacturing optimization are presented if environmental assessments are seen as operational tool. Lastly, the potential of scenarios to enable an operative and process-driven perspective in industry are discussed.

This paper proceeds methodically as follows: The scope includes the discrete manufacturing industry and its unique requirements for future implementation of LCA. These requirements are derived from current literature regarding operative management tools and specifications for LCA procedures. The requirements are translated into a maturity model for the implementation of primary data-based LCA. Based on expert interviews future implementation scenarios for manufacturing companies are derived. Those scenarios are matched with the maturity model using a cost-benefit analysis for implementing the scenarios. By evaluating the individual stages of the maturity model while at the same time quantifying the necessary efforts for the derived indicators, the implementation scenarios can be prioritized.

As a result, this paper systematically states the implementation potentials of LCA in the manufacturing industry, the vision to integrate the tool more into the companies' structures and the needed requirements. It becomes clear which application scenarios of LCA – though resource consuming – have a beneficial potential for SMAs. This paper contributes to the distribution of LCA as an operational tool and holistic thinking across various structures of the company.

1.5. UK Manufacturing's CBAM Preparedness Crisis: Findings from National Implementation Support

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This study examines the critical state of the UK manufacturing sector's preparedness for the EU Carbon Border Adjustment Mechanism (CBAM), based on direct engagement with manufacturers. Our findings reveal concerning systemic gaps in CBAM readiness that threaten UK manufacturers' competitiveness and market access.

We identified multiple critical issues: widespread awareness about CBAM requirements, insufficient internal capacity for emissions reporting, and absence of coordinated national support mechanisms. Most concerningly, our engagement revealed that while EU competitors benefit from structured government guidance and support programs, UK manufacturers are largely left to navigate CBAM compliance independently.

Key findings include:

- *Lack of basic understanding of CBAM implications*
- *Significant gaps in Life Cycle Assessment capabilities needed for compliance*
- *Absence of centralised UK government guidance on CBAM requirements*
- *Limited awareness of verification and reporting requirements*
- *Critical skills shortages in carbon accounting and environmental declarations*

This systemic unpreparedness threatens UK manufacturing competitiveness as CBAM implementation progresses. Without urgent intervention to address these gaps through coordinated policy support and capability building, UK manufacturers risk losing access to EU markets or facing significant compliance costs. Our findings suggest the immediate need for a national CBAM preparedness strategy to prevent the UK industry from falling behind European competitors.

2. Social LCA

2.1. Advancing Social Life Cycle Assessment (S-LCA) in Rural Africa: Methodological Insights and Applications from the H2020 Bio4Africa Project

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In many African countries, agriculture remains the backbone of the rural economy, yet the socio-economic conditions of smallholder farmers and local population face persistent challenges such as low productivity, limited access to markets, low wages, poor health and safety standards, and vulnerability to climate change. Strengthening their economic resilience and improving their livelihoods are critical to ensuring food security and fostering sustainable rural development. Under this context, the research conducted as part of the EU-funded H2020 Bio4Africa project is presented, which promotes the bioeconomy in rural Africa by developing circular bio-based solutions and value chains. The project emphasizes the cascading use of local resources and fostering gender-balanced income diversification among farmers by creating value-added bio-based solutions that enhance agricultural productivity and livelihoods while minimizing environmental impacts. To ensure sustainability, the project assesses the environmental, economic, and social performance of its bio-based solutions across four pilot countries: Uganda, Ghana, Côte d'Ivoire, and Senegal. Life cycle-based approaches are increasingly recognized as valuable tools for advancing sustainable production and consumption practices. However, Social Life Cycle Assessment (S-LCA) remains the least utilized, partly due to the limited emphasis placed on the social aspect of sustainability within the agriculture sector.

This study focuses on the S-LCA of two technologies (Green Biorefinery, Pyrolysis) applied across four product end-uses: (i) animal feed from green biorefineries in Uganda, (ii) biochar as a soil amendment in Ghana, (iii) biochar for water treatment in Côte d'Ivoire, and (iv) biochar briquettes as cooking fuel in Senegal. The study highlights the methodological challenges encountered during the implementation of S-LCA in different pilot contexts. The assessment framework adopts a localised approach to address the social impacts on stakeholders within the studied value chains. Key activities include a literature review on bio-based systems, hotspot identification using the Social Hotspot Database (SHDB) in the openLCA software, and primary data collection through active engagement with local stakeholders. Dedicated workshops with project partners and awareness campaigns with local actors have facilitated the collection of context-specific social data. The Analytical Hierarchy Process was used to prioritise social impact indicators, drawing on expert input in a structured, evidence-based manner. Assessments were conducted using the Performance Reference Points, structured into three dimensions—national, sectoral (agriculture), and pilot-specific—based on available data. By improving agricultural practices and integrating bio-based innovations, the project provides significant added value for food security, equitable income distribution, and improved working conditions in rural communities.

2.2. Social risks of Dutch and Greek economies

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Input-Output Tables show monetary relationships between producers and consumers within an economy and have been used to assess the a few social effects. The objective of this study was to apply Social Life Cycle Assessment (S-LCA) to assess direct social risks of national economies.

A hotspot assessment was conducted using the Product Social Impact Life Cycle Assessment (PSILCA) database to assess the direct social risks of monetary outputs of the Dutch and Greek economies in 2018.

This study showed that the Dutch economy results in lower normalized risk values for all S-LCA stakeholders and impact subcategories, except for "Respect of indigenous rights" and "Health and safety (Workers)". The main contributing parameters were sectorial monetary output and the risk levels of considered indicators.

The results indicate that Input-Output Tables can be extended to incorporate social dimensions with S-LCA and PSILCA. Therefore, S-LCA combined with PSILCA can assist national governments in taking targeted actions to reach SDG targets in the most impactful economic sectors for social performance monitoring and reporting.

2.3. Evaluating social impacts in microalgal biorefineries: A PSILCA-based Social-LCA approach

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Microalgal biorefineries are commonly identified as a potential response to the replacement of fossil-fuel based energy and value-added compounds. The relative easiness in which this type of biomass can be produced, combining atmospheric carbon capture with the low-value industrial side streams valorization, makes them an interesting feedstock. The MULTI-STR3AM biorefinery plans to deliver a complete microalgal biorefinery, focused on the development of various microalgae streams and their processing into protein, carbohydrate and lipidic fractions. These fractions can be used by selected value-chain actors for further conversion into commercially available products, more sustainable and environmentally friendly than their fossil-fuel based counterparts. Given the complexity of the value-chain and the numerous stakeholders involved in the project, the development of the social life cycle assessment (S-LCA) was suggested as a complement to the already well-established economic and environmental assessments. The present study focuses on the S-LCA of a demo-scale microalgal biorefinery for the production and extraction of Nannochloropsis sp. fractions. Data from the foreground system was obtained directly from the site (ALGATEC Eco Business Park, Póvoa de Santa Iria, Portugal) while PSILCA v3.1.1 (Product Social Impact Life Cycle Assessment database) generic data was used for all inputs which could not be independently assessed. OpenLCA v2.3.0 was used for

assessing the social impacts following a cradle-to-gate approach. Social outputs were selected according to the Portuguese social context, project information and appropriate literature. Preliminary results permitted the identification of several hotspots of the production process, particularly those related to the stakeholder workers (fair salary and trade unionism) and society (public expenditures on education and public corruption). A more in-depth analysis of the impact contributions revealed that the foreground system was more strongly linked to economic factors, including the relatively lower impact attributed to the sector's contribution to economic development. Remaining impacts are largely related to upstream data, which should be approached with caution due to its generic nature. As the microalgal biorefinery is still under development, further analysis is needed to integrate more site-specific foreground data. This study aims to serve as a decision-support tool, particularly for key stakeholders with the greatest influence within the organization, enabling them to make informed choices based on a more accurate and comprehensive assessment.

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2.4. Enduring physical hazards and related risks at work - broadening the view on health and safety aspects in PSILCA

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The PSILCA database includes already several indicators addressing health and safety of workers, among them exposure to chemical pollution. For physical hazards, effects of isolated accidents and incidents are represented. For lasting or repeated physical burden, the case is less clear. Enduring exposure to vibrations (hand arm and whole body) are an important contributor to musculoskeletal problems listed in the WHO's 2020 global burden of disease estimate and a recognized occupational disease in industrialised countries. Operating heavy equipment with reduced grip force or dizziness induced by vibrations can also contribute to reduced control and thus increase of accidents as a secondary effect. Based on available data from WHO and ILO combined with publications by national authorities such as the Canadian centre for occupational health and safety, the Swedish work environment authority and occupational disability insurance statistics, constructing a DALY based indicator is a potential corrective action to include a wider set of indicators. Aspects to be addressed are among others availability of representative inventory data from different global locations and industry sectors, alignment and overlap with existing social indicators in the health and safety category for stakeholders workers and induced effects on society as a stakeholder depending on the level of social and labour welfare.

Establishing a new indicator will therefore start with analysing the reasoning and data for existing health and safety indicators in PSILCA, review of background literature and statistics for occupational hazards related to vibrations (and noise), and constructing indicators for a foreground production and use system of power tools and heavy equipment in Sweden. The applicability for other regions and if necessary adjustments will be tested. Preliminary results will be evaluated vis a vis existing indicators *for the stakeholder group worker and where possible society. Guidance and recommendations for broadening social indicator sets will be provided in the conclusions and outlook section.*

2.5. Enhancing the interoperability of the SOCA database for social LCA

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A usual flow of work nowadays to conduct social LCA (S-LCA) requires life-cycle inventory databases, namely databases that describe on the one hand, social flows, and technology related flows on the other hand. PSILCA is an Eora Input Output based database developed to conduct S-LCA. Being based on Multi Regional Input Output (MRIO) tables, PSILCA contains data at country-sector level, specifically in worker-hours per USD of production per country-sector. It provides results in medium risk hours per monetary unit produced. Ecoinvent is a database for environmental LCA that was built with process-level data. Following the current sustainability paradigm, the need to perform holistic assessments from social, environmental and economic perspectives on the same case studies has increased. In this context, Soca is the only database that merges Ecoinvent and PSILCA to allow the practitioner to conduct LCA, S-LCA and LCC within a single process-based database and framework.

The data structure of Soca today, as can be used in OpenLCA includes directly in the different processes of Ecoinvent the flows indicating the different social indicator risks, associated by the location, sector and process. In our work, we explore the pros and cons of representing social flows using this modelling approach. Our investigation starts by identifying the necessary data to reproduce the database contents under another Operational modelling framework for LCA , namely the one of Brightway (another free and open source LCA software). The different challenges related to the usual nomenclature and harmonization issues in the world of LCI databases will be presented as they apply to this case, as well as the potential changes in the modelling principles of Soca required to fit the Brightway framework. After an initial exploration, we have identified an alternative modelling approach for Soca that would allow for an easier update of the related social characteristics, or overall database migrations. Our work has been done within different european research projects, and we derive our lessons learned over different case studies where we use Soca for S-LCA in different application sectors (building/plastics, graphene production, etc.).

3. EPDs in a changing world

3.1. EPDs over time: The case study of Riventi Fachadas Estructurales using openLCA

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Environmental Product Declarations (EPD) play a critical role in promoting transparency in the environmental performance of construction products. This case study examines the evolution of EPDs for Riventi Fachadas Estructurales SL's curtain wall systems, published under The International EPD® System, and highlights the role of openLCA in adapting to methodological advancements and regulatory changes over time.

Riventi's initial EPD, published in October 2017, included four configurations of curtain wall systems, each with two variations: 1) four quadrants of glass and 2) three quadrants of glass and one of composite. The results of each option were presented separately.

In 2022, five years after its first publication, the EPD had to be updated, which required significant adjustments due to updated inventory data and methodological advancements.

Using openLCA 1.11.0 and GreenDelta ecoinvent v3.8 EN15804 add-on v.3 we ensured compliance with the PCR 2019:14 Construction Products (version 1.2.4). This version introduced new requirements, such as reporting worst-case results if impact variations exceeded 10%. As a result, a single set of results was presented to reflect the worst-case scenario for compliance.

In 2024, further revisions to the PCR (version 1.3.4) allowed for the development of product-average EPDs. To meet these updated requirements, a comprehensive LCA was conducted using the latest database and software version: ecoinvent 3.9.1 EN 15804 add-on and openLCA 2.2.0. The updated software incorporated advanced features, such as the ability to incorporate EPDs of specific components from Riventi's suppliers, significantly improving the quality and accuracy of the resulting EPD.

This case study highlights the challenges and opportunities encountered in each update, focusing on methodological changes, the application of new software capabilities, and the decision-making process for presenting results. It illustrates the importance of maintaining compliance while improving the credibility and quality of EPDs over time.

3.2. Regional EPD and CBAM capacity building using openLCA: Lessons from UK SME Implementation

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Life Cycle Assessment is becoming critical for market access, especially with the growth and mass adoption of Environmental Product Declarations (EPDs) and emerging regulations like the Carbon Border Adjustment Mechanism (CBAM).

The Tees Valley Combined Authority's Net Zero project, funded by the UK Shared Prosperity Fund, aimed to understand EPD readiness among British manufacturers. While EPD costs represent one barrier, our implementation uncovered a more fundamental challenge, which we worked to address through training and workshops: a widespread lack of awareness about EPDs, their importance, and their relevance to export. Significant knowledge gaps regarding CBAM were also shown. This knowledge issue and insufficient government guidance on CBAM compliance leave UK manufacturers particularly vulnerable as international supply chains increasingly demand verified environmental and carbon impacts.

The initiative combines direct EPD development for 10 SMEs with broader capacity building across 30+ companies, using openLCA as the core analytical tool. Using openLCA, we developed practical methodologies for companies with no prior LCA exposure, demonstrating how regional support can bridge this knowledge gap. The presentation details:

- Baseline assessment of EPD and CBAM awareness in UK manufacturing

- Development of efficient data collection protocols for resource-constrained SMEs

- Comparative analysis of UK preparedness versus European counterparts

- Strategies for rapid regional capability development

- Policy recommendations for addressing systemic knowledge gaps

The presentation provides quantitative and qualitative evidence of these challenges, offering insights for other regions facing similar industrial transition needs. We conclude with recommendations for policy makers and industrial support organisations to prevent UK manufacturers from being excluded from supply chains requiring validated environmental declarations.

3.3. The role of openLCA in North American EPDs and public procurement

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The use of EPDs to drive public procurement in the United States has recently undergone a process of rapid maturation, from the introduction of Buy Clean California in 2017 through to the passage of the US Federal Government's Inflation Reduction Act and growing adoption of EPDs by state governments for regulatory purposes. OpenLCA has played a critical role in this expansion by enabling the development of an LCI and LCA ecosystem appropriate for both government and commercial investment. We review the role openLCA has played in the establishment and evolution of this ecosystem, from the development of public datasets to the design of Product Category Rules for EPD automation. We further explore the efforts of consultancies and agencies to build, refine, and deploy openLCA-based EPD tools to enable and support US and Canadian regulatory activities and the development of an open, harmonized public and private green procurement landscape.

3.4. Perspectives on the development and implementation of environmental impact communication in the Brazilian road infrastructure sector

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Paved roads represent 12% of the 1,720,909km Brazilian road network, with 23,238km managed by private private concession companies. With thousands of kilometers still not paved and only 34% of the network classified as in good or excellent traffic condition, there is an urgent need for construction and maintenance operations, which means an opportunity to implement practices to reduce associated environmental impacts. Besides the strong public incentives for Environmental Social Governance practices in the Brazilian road infrastructure sector in recent years, there are still no public policies regarding environmental impact communication as a governance strategy. In this context, a Technological Development Project supported by the National Land Transportation Regulatory Agency aims to develop Environmental Product Declarations for asphalt mixtures applied in the duplication service of the BR 153 Highway, one of the most significant road infrastructure projects contracted in Brazil, managed by a private road concession company, which will duplicate 622 km of roadways in the transition between the Amazon and Central South Complex. As environmental impact communication is still not a current practice in the country, developing product category rules for asphalt mixtures appropriate to the local industry context is still challenging. A life cycle conducted using the OpenLCA software and the Ecoinvent database provided environmental impact data for the A1 to A5 stages through different impact assessment methods to support further discussions on potential directives for developing product category rules for asphalt mixtures. An academy-industry knowledge exchange highlighted the role of environmental product declaration to guide strategic initiatives at different levels, assist in decision-making processes, and design business models that meet the country's sustainability requirements for road infrastructure.

3.5. Setting New Benchmarks: EPD Development for Cellulose Ethers with openLCA

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The environmental footprint of products and processes is a growing concern for industries worldwide, and Environmental Product Declarations (EPDs) are increasingly used to enhance transparency and accountability. This study explores the integration of openLCA in the industrial production of cellulose ethers, a key excipient in various applications, including pharmaceuticals, food, and construction materials. The primary objective was to develop a comprehensive EPD, utilizing openLCA to highlight environmental hotspots and opportunities for sustainability improvements.

A cradle-to-grave Life Cycle Assessment (LCA) adhering to ISO 14044 was conducted, with specific attention to the Product Category Rules (PCR) 2021:03 Basic Chemicals. The LCA model was developed in openLCA using global parameters for all input and output values, allowing the manufacturer to easily adapt data without modifying the underlying model. Leveraging the ecoinvent 3.9.1 database, the study replaced secondary data with primary data collected from suppliers at critical ecological hotspots. This shift significantly improved data accuracy and reduced the Global Warming Potential (GWP) by over 40%. Key impact categories were assessed using the PEF 3.1 methodology.

The LCA system boundaries encompassed raw material extraction, transportation, production, packaging, and end-of-life disposal of cellulose ethers. While raw material sourcing accounted for most impacts of the environmental footprint, energy consumption and process media also emerged as significant contributors.

As being the first of its kind in the cellulose ether industry, the resulting EPD represents a pioneering achievement for the cellulose ethers sector, setting a benchmark for sustainability and transparency. The insights gained from this project underscore the importance of supplier collaboration in collecting accurate primary data, which not only enhances the credibility of EPDs but also provides actionable strategies for reducing environmental impacts. By fostering informed decision-making among stakeholders, this work aligns with emerging regulatory and market demands for sustainability.

This case study illustrates the usefulness of openLCA in the industry to streamline EPD development. Future work will explore further reductions in environmental impacts and broader applications of this methodology.

4. Circular Economy

4.1. Using the Circularity Package for openLCA to implement the comprehensive Orienting framework covering Life Cycle Sustainability Assessment as well as resource circularity and criticality for the case of direct recycling of lithium iron phosphate (LFP) batteries

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The increasing demand for lithium iron phosphate (LFP) batteries, primarily driven by their extensive use in electric vehicles (EVs) and energy storage systems, presents a significant challenge in terms of managing end-of-life (EoL) batteries and production waste. LFP batteries, favoured for their safety, longer lifespan, and cost-effectiveness, contain fewer valuable metals compared to other lithium-ion chemistries, such as nickel-cobalt-manganese (NCM) and nickel-cobalt-aluminium (NCA). This characteristic makes traditional recycling processes like hydrometallurgy and pyrometallurgy less economically viable for LFP batteries.

In response to the challenges mentioned above, the ReUse project aims to develop innovative, direct recycling processes specifically for LFP batteries. These processes focus on recovering valuable active materials (such as cathode and anode) with high purity, which allows for their reuse in new battery production. An additional challenge addressed by the ReUse project is the criticality of certain battery materials. Lithium, in particular, is a strategically critical metal, and ensuring its efficient recovery and reuse is essential to reduce dependency on new material extraction and to mitigate risks related to assess to this resource. By focusing on circularity, the ability to recover, recycle, and reuse materials within the production cycle, the ReUse project seeks to minimize environmental impacts, including greenhouse gas (GHG) emissions, resource depletion, and waste generation. Ensuring compliance with the EU Batteries Directive and promoting the efficient recovery of critical materials such as lithium are essential for securing a sustainable, circular economy.

Given these challenges, the comprehensive Orienting framework covering Life Cycle Sustainability Assessment (LCSA) as well as resource circularity and criticality has been retained for evaluating the environmental, economic, and social sustainability as well circularity and criticality of the direct recycling processes being developed. As tool OpenLCA with the Circularity Package has been chosen. This extended LCSA will provide a comprehensive analysis of the impact of the recycling routes, guiding the project towards reducing environmental burdens and supporting the circular economy. First experiences in carrying out this comprehensive assessment, in particular with the application of the Circularity Package for openLCA, will be presented.

4.2. Cradle-to-Grave Life Cycle Assessment of Novel Hybrid Glass-Metal Fibre Reinforced Polymer Composites – Comparing the Environmental Impact of Recycling Technologies with Conventional Disposal Routes

Ebyan Rezgui, Alexander Koch

GreenDelta, Berlin, Germany

Over the last 30 years, fibre reinforced polymer (FRP) composites have seen widespread adoption across numerous sectors due to their exceptional mechanical properties and low weight. In addition to these performance benefits, weight reduction of components through use of hybrid composite materials also offers the potential for both material resource and CO2 savings. Despite this, the disposal of these materials remains problematic, with the majority of composite waste globally sent to landfill or incinerated due to a lack of technology and infrastructure for recycling.

In the BMWK funded project "Hybrid Switch", a cradle-to-grave LCA approach was taken to compare the environmental impact of two hybrid glass-metal fibre composite components – drop side walls for commercial vehicles and pipe connectors for gas and water pipelines - with conventional technologies throughout the production, use and end-of-life phases.

This presentation will outline how :

1. Parametrised models of novel manufacturing techniques were developed in openLCA to compare GWP impact of hybrid composite components with conventional technologies.

2. Approaches for modelling the end-of-life of glass FRP materials were adapted to a hybrid composite context to determine to what extent increased impacts from the end-of-life phase can outweigh decreased impacts during the use phase.

The implementation of this model allows the manufacture and design of hybrid composite components to be optimised to maximise recycling efficiency, as well as informing the further development of recycling technology and infrastructure.

4.3. Lifecycle Modeling of Repair vs. Remanufacturing. Evaluating Circular Economy Practices for Automotive Electronics

Naila Rana Andira, Dr. Fernando Penaherrera

OFFIS, Oldenburg, Germany

This study assesses the life cycle impacts of an electronic control unit for the automotive industry, comparing the environmental benefits of repair versus remanufacture. The European Union has launched several directives and proposals to improve circular economy by encouraging repairability, reusability, and extension of the service life of equipment. These measures aim to address environmental issues like greenhouse gas emissions, (critical) resource depletion, and biodiversity loss. Electronic component manufacturing is one of the sectors highlighted due to its energy-intensive manufacturing, consumption of scarce materials, high circularity potential, and the rapid growth of *waste electrical and electronic equipment due to short product lifespans. Quantifying the environmental benefits of repair can drive improvements in the repairability of electronics. While research increasingly emphasizes the environmental impacts of electronic components, challenges persist in modeling circular economy practices. Complex process systems for repairing and limited data on the processes and inputs hinder comprehensive evaluations. This study evaluates the Life Cycle Impacts of a specific electronic product, designed as "electronic control unit", used in the automotive industry, and compares the environmental burdens of repairing and reusing parts of the unit over its life cycle. Data on material composition, manufacturing energy consumption, and processes were collected as a baseline for the Life Cycle Impact Assessment. A repair model was developed, incorporating firsthand information from manufacturers to evaluate the environmental benefits of repairing damaged units. Several parts are modeled as either repaired or reused. Key findings highlight significant greenhouse gas emissions from energy-intensive manufacturing of electronic pieces and plastic parts. Material depletion impacts are primarily linked to the production of parts containing base metals. Repairing reduces emissions compared to remanufacturing, though some processes for key components remain resource-intensive. This research demonstrates the utility of firsthand data in assessing circular economy practices like repair and recycling. Repairing damaged units can significantly mitigate environmental burdens, offering a practical pathway to sustainability. The methodology developed here can be applied to other electronic components, promoting sustainable practices across industries and encouraging greater focus on improving the repairability of electronic products. Quantifying lifetime impacts provides critical insights into the broader benefits of circular economy strategies.*

4.4. Advancing Microfiber Waste Treatment: LCA of Thermochemical Upcycling of laundry microfibers from TRL3–TRL4.

miss Silvia Parrilla-Lahoz[1],[2], Miss Shravya Hebbur Murali[3], Mr Tomas Ramirez-Reina[4], Ms Melis Duyar[1]

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Microplastics exist in various forms and dimensions, with the fibrous or filamentous type being the most prevalent. Microfibers predominantly originate from the laundering of synthetic textiles in both home and industrial settings, accounting for 35% of the detected microplastics in aquatic ecosystems [1]. The release of microfibers during washing is influenced by washing cycles, detergents, temperature, water hardness, and textile construction [2]. Various regions, such as California, France, and Australia, have implemented substantial initiatives to address the problem of microfibre emissions. Thermochemical Upcycling techniques enable the production of valuable carbon products from collected microplastics [3] . In specific, pyrolysis is a chemical process that involves the decomposition of organic materials at elevated temperatures in the absence of oxygen and hydrothermal carbonisation is a thermochemical process that involves converting organic materials into a carbon-rich material called hydrochar through the application of heat and pressure in the presence of water. This study optimises upcycling technology and minimises environmental impacts by comparing end-of-life treatments with traditional methods to create graphite and amorphous carbon. Laboratory results scaled both technologies from TRL [3]-[4] to TRL 6-7 through assumptions, excluding machinery and *maintenance. The study uses two unique environmental effect assessment methods: conservative and Allocation at the Point of Substitution (APOS). This dual approach ensures a complete awareness of upcycling's environmental benefits and drawbacks.*

openLCA software is used to perform an ISO 14040 (ISO, 2006) compliant Life Cycle Assessment (LCA) study with the ecoinvent database (specifically ecoinvent 3.10 cutoff unit process)4. The LCIA Method selected was Environmental Footprint reference package v3.1. (E.F. 3.1) released in July 2022 by the European Commission. The weighted impact assessments indicate that climate change and eutrophication of fresh water are the impact categories that have a higher environmental impact therefore are the focus of the study. Results show that the electricity market emerges as the major contributor across both categories, indicating that electricity generation and consumption play a substantial role in driving these impacts. The power market is the spotlight, underscoring the necessity to transition to renewable energy and enhance energy efficiency to alleviate environmental consequences. The study concludes with a sensitivity analysis of the technology's environmental performance across different electrical grid compositions, including more renewable energy. This comparative analysis shows how renewable energy integration affects technological sustainability and promotes its growth in green energy grid locations.

4.5. Assessment of the environmental impact of destroyed unsold products

Dr. Vincenzo Senatore

European Commission Joint Research Centre, Sevilla, Spain

The recent enforcement of the Ecodesign for Sustainable Products Regulation (ESPR) represents a significant advancement in the European Union's commitment to sustainable development and the potential to mitigate unsustainable practices. The introduction of the ESPR, in particular Article 24, has prompted efforts to reduce the environmentally damaging destruction of unsold products. The overarching objective is to achieve a substantial reduction in the Destroyed Unsold Products (DUP) through enhanced transparency and accountability. In accordance with this regulatory framework, the Joint Research Centre (JRC) has initiated a comprehensive research programme with the objective of developing a mandatory disclosure format and a methodology for assessing the environmental impact of the DUP. The JRC's objectives can be broadly categorised into two distinct areas of focus: firstly, the development of a standardised reporting format that will require economic operators to disclose information on unsold products; and secondly, the creation of an analytical methodology to assess the environmental impact of their destruction. The research presents a number of significant challenges, including the design of an intuitive reporting format, the determination of the optimal product classification code system (e.g., CN or Prodcom), and the definition of the required information granularity, reflected in the specificity of the code digits (e.g., 2, 4, 6 and 8). A crucial element of the environmental assessment is the selection of an appropriate functional unit (FU) within the life cycle assessment (LCA) framework. This will serve as the benchmark for quantifying the environmental footprint of the DUP.

The LCA stages that have been the subject of greater scrutiny are the extraction of raw materials (considering the unused potential), the logistics and end-of-life. This approach ensures that all relevant environmental dimensions, in particular the unused material potential, are taken into account.

As the research progresses, the next steps will be to finalise the draft format based on stakeholder consultations, refine the LCA methodology and propose practical solutions.

It is evident that a transformative policy framework, in conjunction with robust, data-driven research, is indispensable for mitigating the environmental impact of unsold consumer products and facilitating the transition towards a more sustainable and circular economy.

5. openLCA Tools and Integration

5.1. Automating Life Cycle Assessment with Python Integration via OLCAClient and Large Language Models for higher efficiency in environmental data management

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Life Cycle Assessment (LCA) is an essential tool for companies seeking to evaluate and mitigate the environmental impacts of their products and processes. With growing regulatory requirements, including mandatory sustainability reporting and compliance with environmental standards, businesses, particularly small and medium-sized enterprises (SMEs), encounter significant challenges in performing comprehensive ecological assessments. The complexity of LCA methodology, resource-intensive data handling, and the necessity for expert knowledge often impede timely and accurate evaluations, complicating efforts to comply with legal obligations and meet market expectations for transparency.

"LCAutoPilot" is an initiative aimed at transforming the LCA process through automation and artificial intelligence, utilizing open-source technology accessible to all. Our goal is to create a tool that automatically converts Excel-based bills of materials (BOMs) into detailed LCA models. This strategy seeks to decrease manual labor, reduce errors, and lower the expertise barrier. The tool requirements include:

1. *Integration with OpenLCA*
2. *Automated reading of Excle-based BOMs*
3. *Creation of processes, flows, and product systems*
4. *Hierarchical linking and accurate reproduction of product systems*
5. *Automated connection with background data from a database, including quality checks*

To date, we have successfully developed a Python script that addresses requirements 1 to 4 and are currently researching function 5. OpenLCA integration was achieved through the OLCAClient class, which connects to OpenLCA software using an IPC interface (Inter-Process Communication). The ExcelReader class reads the relevant data within the Excel file, such as weight, material, quantity, and product structure for LCA modeling. The script generates corresponding processes and flows for each component, defining input and output exchanges based on specified weightings and hierarchies. Processes are then linked according to hierarchical levels to reflect the production system structure.

Research continues on automated linking of background data, focusing on the integration of Large Language Models (LLM). Currently, the linking to e.g. ecoinvent database still requires manual selection of suitable providers within the BOM. The proposed concept involves utilizing the olcaClient to retrieve data from the database, linking process descriptions with material designations in the BOM via an LLM. The match probability and quality matrix will also be provided, ensuring dataset accuracy and quality.

The work on LCAutoPilot represents a significant advancement in enhancing environmental assessment efficiency through automation and digitalization, promoting broader adoption of sustainable practices across industries. The upcoming presentation will delve into the initial findings and discuss the future of AI in LCA modeling.

5.2. Automated Life Cycle Analysis using the System Modeling Language v2 and OpenLCA

Hamza Bassam, Axel Scheithauer

oose, Hamburg, Germany

The International Council on Systems Engineering (INCOSE) has identified, in their Systems Engineering (SE) Vision for 2035, sustainability as a megatrend that will shape the future of engineered systems. Engineers will increasingly be expected to consider the societal and environmental impacts of systems as an integral part of their work. This presentation introduces a novel approach leveraging Model-Based Systems Engineering (MBSE) to facilitate and streamline Life Cycle Analysis (LCA). By integrating the System Modeling Language v2 (SysML v2) using its API, and the OpenLCA tool, we demonstrate how LCA can be automated from a SysML v2 model. This automation not only enhances the efficiency of performing LCA but also makes the process more accessible to engineers working within an MBSE framework.

5.3. LCA4Sim – Bringing CADMOULD and openLCA together to facilitate predictive life cycle assessments in the injection molding industry

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The polymer manufacturing industry has been experiencing rapid growth of 363.8 million tons globally from 1976 to 2023 due to increasing global demand for polymer-based products (Statista, 2024). The injection molding process is a polymer-processing method that is used in a wide range of applications. Its major advantages lie in the high degree of design freedom of the tools used and thus of the resulting components as well as in the high throughput potential for manufacturers. Process control is an important aspect, especially for the implementation of injection molding on an industrial scale, since the various parameters have a major influence on the quality of the components and process stability, but also a strong impact on energy consumption. The optimization of process control can be achieved using simulation software such as CADMOULD.

As a very energy-demanding industry, there is a need to increase energy-efficiency for sustainability targets to be met. Life cycle assessment (LCA) is an important tool for gaging these targets. Until now, LCAs were usually carried out after the development of new components and processes. At this point, however, the findings obtained can no longer be incorporated into the design of machines and components, or only at great expense in terms of time and money. An accompanying ecological evaluation of the processes and materials therefore offers significant advantages and potential. As software like CADMOULD allows for the modelling of injection molding processes, it also has the potential to model environmental impacts like global warming potential when combined with LCA software such as openLCA and thus allows for predictive LCAs.

To allow for the realization of these predictive LCAs, a parameterized cradle-to-gate foreground model was developed based on the UVEK database, comprising the stages from the resource extraction to the manufacturing of the injection molded part (which served as the functional unit). The parameters for this model could be set within CADMOULD after connecting with openLCA's IPC server through the openLCA API. The insertion of these parameters would trigger an impact calculation, the results of which could then again be displayed in CADMOULD.

With this, the project LCA4Sim has, for the first time, demonstrated that the programmatic combination of process control and predictive LCA is possible within the context of injection molding.

References:

Statista (2024) 'Annual production of plastics worldwide from 1950 to 2023' [online]: Hamburg, Statista. Available from: https://www.statista.com/statistics/282732/global-production-of-plastics-since-1950/ [accessed 27 November 2024].

5.4. Exploring the Integration of openLCA in Higher Education: lessons learned from the M. Sc. Programme Urban Technology at the Amsterdam University of Applied Sciences.

ir Tony J.N. Schoen[1], dr. ir. Natascha M. van der Velden[2], dr. ir. Kasper P.H. Lange[1]

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Research and education on circular products and systems design have gained ground in universities globally for the past 10 years. In 2023, the Circular Design and Business research team at the Amsterdam University of Applied Sciences (AUAS) explored how students and researchers could best assess the environmental impact of product and systems designs. In their search for suitable instruments, it was decided to explore whether openLCA would meet their needs, specifically to support engineering students and applied researchers. Arguments for this were the low threshold and accessibility of the developing community and the possibility of using recognized datasets and methods (such as ecoinvent, CML, and EF). In the academic year 2024/25, openLCA was introduced in a teaching *module in the M. Sc. programme Urban Technology to support graduates in determining the environmental impact of products and urban system designs.*

The focus of the M. Sc. programme is how to create the sustainable, liveable and accessible city of the future, working interdisciplinary and systematically on technical solutions to these challenges. Students are offered a range of tools to design system solutions and evaluate the impact of their choices. It is the research team's ambition to add openLCA to the toolbox.

The LCA module includes an online introduction course on the principles of LCA, five interactive lectures, and a self-study tutorial based on the existing openLCA tutorial, adapted and expanded to the specific needs of AUAS. Furthermore, the module uses openLCA to evaluate two student assignments: urban waste collection systems and reusable food packaging systems. In this paper, the authors evaluate the module and case assignments to assess how openLCA contributes to higher education. It will further address the understanding of using openLCA in higher education by exploring the factors influencing learning about LCA. The paper will provide recommendations for educators and researchers in M.Sc. programmes and explore the potential to introduce openLCA in AUAS Bachelor's progammes (which are the core of AUAS), contributing to the further development of openLCA to improve environmental impact assessments of products and systems in education.

The development of the teaching module in the M. Sc. programme was financially supported by the Center of Expertise City Net Zero at AUAS.

5.5. PRIMUS' LCA tools with the connection to a traceability system

Julia Cilleruelo Palomero, Megha Mittal

GreenDelta GmbH, Berlin, Germany

As part of the PRIMUS project, and in collaboration with the whole consortium for data collection, context and blockchain communication, GreenDelta GmbH developed an expert and non-expert sustainability tool for plastics and recycled plastics supply chains (flake, pellet and plastic part). The expert tool is based in openLCA, the open source and freely available LCA software developed since 2007, and contains a database and LCA model for LCA, SLCA, LCC, Circularity and Plastic Littering assessments, following the sustainability methodology developed in the project. Furthermore, the tool connects to the Circularise blockchain system (not open source) through an API to obtain supply chain information and give back LCA results. This tool is directed to LCA practitioners performing sustainability studies for recycled plastic products and related. The non-expert tool is directed to actors in the recycled plastic life cycle, from recyclers producing flakes, to compounders producing pellets, to plastic part producers that would like to incorporate recycled plastics in their production. These users are interested in their environmental impact but don't have the resources or personnel for performing full LCAs. The tool is based in excel with a user-friendly interface where the user is guided along data collection, input and results.

This talk will focus on the PRIMUS expert tool, specifically on the connection with a supply chain traceability system

5.6. onlineLCA, scaling LCA for non-specialists

François Le Rall, Bach Tran, Mubeena Hamza, Michael Srocka, Dr Andreas Ciroth

GreenDelta GmbH, Berlin, Germany

With Life Cycle Assessment (LCA) becoming a mainstream tool for sustainable decision-making, there is a growing need to make LCA accessible to a broader audience beyond specialists. onlineLCA is a web-based application designed to bridge this gap by enabling streamlined adaptation, calculation, and analysis of LCA models. Developed over the past 2.5 years, the system leverages openLCA as its modeling and calculation engine and integrates a web interface for easy usage.

onlineLCA empowers non-specialists to interact with pre-approved, high-quality models created by LCA experts. Through a user-friendly interface, users can modify specified parameters and adapt models to their needs while maintaining data integrity. The platform features robust user rights management, ensuring secure access to models, data, and calculation options. It operates on enterprise cloud systems or dedicated GreenDelta servers and connects seamlessly to company data sources using openLCA's IPC server API.

onlineLCA offers a range of features, including parameter settings, results visualization (e.g., contribution tree, provider map, Sankey diagram, Sunburst diagram, and more), system comparison, setup saving and sharing. One of its key strengths is adaptability: recognizing that every company has unique requirements, onlineLCA can be customized to provide only the necessary functionalities. Additionally, onlineLCA is particularly effective for automatically generating reports from LCA results using predefined templates.

This presentation will showcase the onlineLCA application, focusing on its architecture, features, and real-world implementations.

5.7. EcoOptiPack – Using openLCA and onlineLCA for an easy-to-use assessment tool for plastic packaging

Dr Friedrich Halstenberg, François Le Rall

GreenDelta, Berlin, Germany

Plastics are widely recognized as versatile and highly functional materials, particularly in applications like packaging. By consistently incorporating recycled materials into plastic products, emissions (such as CO_2 and the release of macro- and microplastics into water bodies) and the reliance on petroleum can be significantly reduced. To enable the reliable industrial use of recyclates, the innovation lab "KIOptiPack - Design and Production" focuses on improving material quality.

Within the project, EcoOptiPack was developed to simplify the sustainability assessment of plastic packaging with recycled content for end users. As a basis for implementation, onlineLCA was used. In the applied framework, openLCA serves as the engine and modeling tool for the system. Experts create models in openLCA, which are made accessible via its API to the onlineLCA web tool. The web tool features user rights management, enabling users to modify models based on their permissions. Common modifications include changes to materials, dimensions, transport distances and modes, and end-of-life options. This setup allows team members across an organization—whether in product development, marketing, procurement, or management—to explore variations and options quickly, securely, and accurately, without needing detailed knowledge of LCA modeling or regulatory compliance. Results can be reviewed and converted into reports or documentation, customizable to company templates within onlineLCA. This approach enables enterprises to scale LCA capabilities efficiently and effectively.

In the basic version of EcoOptiPack, the tool can evaluate mono-material plastic packaging with up to four components, such as the body, lid, closure, and label, made from materials like HDPE, LDPE, PP, PS, PET, and PVC. The tool allows to adjust the amount of recycled and virgin plastic in each component, including materials like rPP, rHDPE, and rPET. The user can also select the manufacturing process for each part, such as injection molding, thermoforming, blow molding, or different extrusion methods. Additionally, the user can input the recyclability of the entire packaging or individual components to assess its end-of-life impact. A Digital Product Passport (DPP) can be uploaded to automatically provide required data, eliminating the need for manual input. This feature is currently available for specific demonstrators in partnership with R-Cycle. Further planned software modules of the tool include a connection to a CAD tool for injection moulding, a specification of individualized production processes and the inclusion of re-use scenarios.

6. Broader Sustainability Assessments

6.1. Applying system dynamics sustainability assessments (SDSA) to assess circular economy solutions in cities and regions

Alexander Koch

GreenDelta, Berlin, Germany

Life Cycle Sustainability Assessment (LCSA) has seen an increasing uptake in the past years, promising a comprehensive assessment of sustainability over the life cycle, with a consideration of environmental, economic, and social impacts. Yet, a linear life cycle model as used in LCSA struggles to reflect some key concepts of sustainability, including context indicators, thresholds and possible non-linear system behaviour, as well as system transition scenarios. With these limitations, LCSA has often failed to capture the true enablers and benefits of circular economy (CE) solutions.

In the EU-funded Horizon project TREASoURcE, a novel sustainability assessment approach that combines system dynamics with LCSA was developed and applied. This approach was developed to overcome limitations of LCSA, while offering a practical modelling and assessment approach for stakeholders in CE decision-making positions. It comprises of two linked parts: (1) a system dynamics model that includes market data and context indicators that influence system behaviour, and (2) a prospective LCA model, implemented in openLCA, that calculates environmental impacts over time.

In the presentation, first, the novel approach will be introduced, and, second, a case study application for plastic value chains in the Nordics will be demonstrated. The simulation results show different plastic CE strategies for different regions in the Nordics. By including context indicators, such as infrastructure accessibility, technology adoption, and regulatory support, and simultaneously calculating environmental impacts, further insights into the feasibility of CE solutions for specific regions emerged. Such a new approach enables the assessment of the transferability and replicability of CE solutions, essentially accelerating their implementation through well-supported decision-making.

6.2. Application of the "at the point of substitution" system model for end-of-life recycling of a corrugated box with multifunctional applications.

Mr Edwin Botha, Dr Kevin Harding

School of Chemical and Metallurgical Engineering, University of the Witwatersrand, Johannesburg, South Africa

Modelling end-of-life (EoL) recycling in life cycle assessments (LCA) can be complex. Among the various models available, the "At the Point of Substitution" (APOS) method stands out as particularly interesting. This approach shares the responsibility for waste between producers and subsequent users who benefit from the waste's treatment. However, only a limited number of studies have tested this method, typically focusing on a single product with a specific use or function. This raises an important question: how can we evaluate the shared impact of a single product that serves multiple functions? This study aimed to analyse the collective impact of corrugated boxes used for packaging five different

products: orange citrus fruit, a television, a bicycle, cotton t-shirts, and a small office desk. The life cycle impacts of these boxes were compared in two scenarios. (1) Assessing the shared burden of each box at the end of its life, based on the product it was carrying, and (2) examining the shared burden of each recycled box, which was integrated into the life cycle of a new box manufactured from these recycled boxes and compared to a new virgin box. The results indicated that the shared burden of each box was significantly affected by the material it contained. The box made from recycled orange citrus fruit boxes had an environmental burden that was 34.7% lower than that of its original virgin box. In contrast, the box made from recycled television boxes had a burden that was 44% greater than its virgin counterpart. Additionally, the environmental impacts of the boxes made from bicycles, t-shirts, and small desk boxes were lower than those of virgin boxes, showing reductions of 16.1%, 18.7%, and 32.8%, respectively. The results of the study indicated that the APOS model is significantly influenced by the environmental burden of the product it carries and its assigned market value. As a result, recycling is predominantly favoured only when the product has a high value and/or a low environmental impact. Given the varied results produced by the APOS model, it was concluded that this model should not be used for legislative processes or sustainability assessments where constancy is crucial, nor in situations where the outcomes could impact incentives or tax considerations. Nevertheless, the APOS model remains a valuable tool for optimizing product design and for sourcing packaging alternatives that originate from cleaner virgin materials and low-impact recycling processes.

6.3. LCSA and beyond: a demonstrator case study using LCSA, plastic littering, circularity and system dynamics for the PRIMUS project

Julia Cilleruelo Palomero, Andreas Ciroth, Ashrakat Hamed

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Life Cycle Sustainability Assessment (LCSA) is widely used for "full" sustainability assessments but also has its limitations: it can only assess as many impact categories as available in the LCIA method, often missing the broader perspective of how the system under study interacts with the world that surrounds it, and vice versa. Things like plastic littering and circularity perspectives are currently missing from LCSA methodology framework.

As part of the European research project PRIMUS for plastic recycling and circularity within high-value product applications, this research proposes an extended methodology for sustainability assessments. It combines work for environmental and social Life Cycle Assessment (LCA) with extensions of LCA databases that can account for plastic littering (PLEX, [1]) and circularity (Circularity Package, [2]). Furthermore, the context of security of supply and recirculation of unwanted substances is investigated using a System Dynamics model.

The presentation thought for the conference will present results for a PRIMUS demonstrator case where the methodology developed is applied.

[1] https://nexus.openlca.org/database/PLEX

[2] https://nexus.openlca.org/database/Circularity%20Package

6.4. Exploring New Frontiers in Absolute Sustainability: Cybernetic Democratic Economic Planning

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The interconnected social, economic, and ecological relationships have culminated in a socio-ecological crisis. This crisis is characterized by the unequal satisfaction of societal needs, which is intrinsically linked to the significant transgression of planetary boundaries. Recent advancements have sought to integrate planetary boundaries (PB) into Life Cycle Assessment (LCA), enabling meso- and macroeconomic evaluations using sector- and product-specific bottom-up approaches. In this context absolute sustainability assessments emerged, which aim to determine the sustainable production quantities of a product. However, robust methodologies for such assessments in LCA remain underdeveloped. This is due to technical and political complexities and challenges associated with sharing principles and applying distributive justice theories across sectors and regions. These issues inevitably raise fundamental questions about political economy and ecology, particularly: How can economies be organized and evaluated to meet societal needs within planetary boundaries?

Interdisciplinary discussions on democratic economic planning (DEP) offer promising insights for addressing these challenges. Planning, understood as the long-term organizational anticipation of actions, is already inherent in current economic systems. Building on this foundation, I propose an approach to cybernetic democratic economic planning. This approach utilizes the HILCSA (Holistic and Integrated Life Cycle Sustainability Assessment) LCIA method and the soca database, both implemented in openLCA.

Via the HILCSA framework over 100 socio-ecological and economic indicators are assessed and aggregated into synthetic units of accounting, referred to as tokens. These tokens represent raw material consumption (RMC), climate change (CC), and working time (WT). By downscaling planetary and social boundaries to per capita budgets, and subsequently allocating and upscaling these budgets to four economic sectors—individual consumption, productive consumption, reserves, and care & infrastructure—this approach enables a comprehensive LCA-based proportioning and impact assessment of underlying production systems.

For an initial allocation of sectoral budgets, the concept of decent living standards (DLS) is employed. A feedback mechanism between production impacts and sectoral budgets facilitates self-regulation within the system. Furthermore, the tokens of RMC, CC, and WT are used to calculate synthetic prices, incentivizing sustainable consumption patterns. In order to account a complex economic system and to simulate the behaviour of its agents, Input-Output (I/O) and Agent Based Modelling (ABM) will be applied in the future.

This cybernetic democratic economic planning framework offers a tool for democratic decision-making, striving to achieve a good life for all within planetary boundaries. It also marks significant progress in methodological advancements toward absolute sustainability assessments.

7. Advancing LCA Databases and LCIA

7.1. Advancing LCA Data for a Harmonized Future: Updates on the TianGong Initiative and Database

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Last year, at the first openLCA conference, we introduced the TianGong Initiative and its accompanying database as a pivotal endeavor aimed at advancing the field of life cycle assessment (LCA). Our mission is to develop a robust, open, and transparent LCA background database, particularly for China, that serves the global LCA community. Over the past year, significant progress has been made in expanding the data coverage and volume, aligning with the growing demand for accurate and consistent LCA data worldwide. One of the key milestones has been the development of an artificial intelligence (AI)-native tool that enhances the database's compliance with the International Reference Life Cycle Data System (ILCD) guidelines. This tool optimizes data management processes, making it more efficient and adaptable to the rapidly evolving needs of the LCA community.

The TianGong Initiative, led by Tsinghua University, brings together a network of over 180 researchers and 43 investigators working collaboratively to build and maintain the TianGong Database. This open-source platform has garnered substantial global engagement, with over 15,000 unique visitors and 20,000 downloads from more than 88 countries. In line with global standards, the database is designed to be transparent and comprehensive, offering high-quality life cycle data that is traceable, verifiable, and fully documented.

However, despite the advances in data collection and processing, challenges related to data interoperability and harmonization persist. Discrepancies in data development methodologies, reference systems, and barriers to data sharing remain significant obstacles to achieving consistent and comparable LCAs. Data isolation, resulting from incompatible software, data formats, and transformation errors, exacerbates these issues, leading to errors and information loss. These challenges hinder the seamless integration of data across different platforms, impeding the potential for cross-border collaboration and large-scale adoption of LCA practices.

To address persistent challenges in data interoperability and harmonization, we envision a unified global framework for LCA data. This framework will focus on standardizing unit processes, nomenclature, and classifications across databases, promoting transparency, traceability, and verifiability of all life cycle inventory data. By fostering global cooperation and encouraging the use of open-source tools for data producers, we aim to enhance the consistency, comparability, and overall quality of LCAs, ensuring better alignment with global sustainability goals.

7.2. New Data for OpenLCA: Expanding Coverage for Chemicals & Plastics

Arne Kaetelhoen

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Chemicals are used in over 95% of manufactured products, making sustainable chemical production essential for the sustainability transition across nearly all sectors. Life Cycle Assessments play a key role in informing this transition, but the application to chemicals is often hindered by gaps in Life Cycle Inventory data for many substances and regions. To address these data gaps, Carbon Minds has developed a Life Cycle Inventory Database covering over 1,300 chemicals and plastics across 200+ regions. Unlike other databases, it models large-volume chemical production with plant-level data, providing unmatched granularity and regionalization. In the beginning of this year, the database was fully integrated into OpenLCA, adding over 100,000 datasets on chemicals and plastics. In this presentation, we will discuss the database's scope, methodology, and certification. We will demonstrate how users can utilize this data to enhance Life Cycle Assessments and identify ways to reduce environmental impacts across chemical supply chains, contributing to the sustainability transition across multiple sectors.

7.3. Parameterized model and region-level life cycle inventory database development for electricity in China

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Electricity serves as a fundamental energy source that is crucial for China's efforts to achieve the dual-carbon goal, and the accuracy of its carbon footprint significantly impacts the quantification of the carbon reduction effect of products in other industrial sectors. To properly account for and reasonably quantify electricity carbon emissions using life cycle assessment (LCA), a high-quality electricity life cycle inventory (LCI) database for China is urgently established. In this study, we developed localized theoretical and empirical parametric models based on official statistics and peer-reviewed publications for China's major forms of power generation (e.g., coal-fired, natural gas-fired, hydroelectric, wind, photovoltaic, and nuclear power generation). The theoretical parametric model integrated key parameter-region mapping relationships and was embedded in the LCI dataset for fossil fuel-fired power generation, e.g., fuel quality and fuel consumption in different regions. The empirical parametric model was conducted by collecting data on power plants and units with varying technical specifications and standardizing them into the unit product. Combining the distribution of different technology specifications across regions, technologically representative and region-specific LCI datasets were generated for renewable energy power generation. At the transmission and distribution (T&D) stage, a configurable traceability model was constructed by voltage levels (e.g., ≥220, 110, 35, 10, and <1 kV) to effectively track the carbon shifts resulting from inter-provincial electricity trade and carbon flows within China's power system. The database tracks and quantifies the carbon emissions of electricity throughout the entire process from production, transmission, conversion, and distribution to consumption. It is fine-grained to the provincial level and reflects regional heterogeneity, which is particularly important for China with a vast geographical area and uneven distribution of energy resources. Given China's dominant position in the global energy market, the database provides a solid basis for quantifying the carbon footprint and environmental impacts of China's power sector, which is

critical for global power assessment, scientific carbon reduction decision-making, and sustainable industry development.

KEYWORDS: life cycle assessment; carbon footprint traceability; modularization; data model.

7.4. The MSDB in comparison to other databases

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The MSDB has been released as a somewhat different LCA database, with 500,000 datasets for all kinds of products, for all regions worldwide.

The creation of the database, from a combination of top-down structuring, bottom up open data, verification points, and artificial intelligence will be summarised. The main part of the presentation will compare the MSDB to other LCA databases (input/output databases, system process and unit process databases). For one, datasets have a slightly different structure in the MSDB; they are unit processes that contain a structure of information "buckets" filled with best available information, and an assessment of the quality of this information. As a result, the datasets are more detailed, and it is always possible to provide a dataset for any product. This difference will be shown using example datasets on agriculture, electronics, and transportation. Further, the database is less static and more connected, as its processes are created from a knowledge base with connected rules and data sources. This flexibility will be demonstrated in the presentation as well, by adding a new data source to the knowledge base and showing the effect on datasets and their data quality.

The presentation will conclude with a discussion on the use of the database, again in comparison to other LCA databases.

7.5. Automated LCI Data Generation for Fine Chemicals via Retrosynthesis

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Life Cycle Assessment (LCA) is a crucial tool for evaluating environmental impacts, yet fine chemical industries face persistent challenges, including data scarcity, confidentiality concerns, and the difficulty of accurately modeling industrial-scale production. To address these barriers, we propose an automated retrosynthesis algorithm designed for industrial applicability. This one-step approach integrates neural networks and advances the AIZynthfinder framework, enabling the systematic breakdown of complex molecules into industrially relevant compounds linked to the cm.chemicals database.

Our approach allowed the calculation of Product Carbon Footprints (PCFs) for 37 plasticizer molecules, which were cross validated against an expert model on equations suggested by our chemistry experts (MRSE=0.7). Thus, demonstrating high comparability and validating the accuracy of our fully automated approach.

This methodology was then scaled to a dataset of 12633 'druglike' molecules, successfully solving reaction pathways for a significant portion (2731) of the compounds. Routes for thousands of molecules were generated showcasing its efficiency in solving reaction pathways.

By bridging data gaps and enhancing the efficiency of traditional LCA modeling, this tool addresses critical needs in the fine chemical industry. It not only accelerates the generation of Life Cycle Inventory (LCI) data but also enables informed decision-making toward more sustainable production processes. Ultimately, our approach represents a step forward in integrating computational innovations into environmental impact assessment and fostering environmentally responsible practices in chemical manufacturing.

7.6. Advantages of Software-Agnostic DSL to tackle reproducibility LCA Databases

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OpenLCA as free and open-source software (FOSS), enables transparency and collaboration in addressing critical challenges in the field from the "tooling" side. However, challenges in reproducibility of sustainability assessments remain, when different tools are used by different LCA practitioners and stakeholders: different databases, different tools (proprietary and FOSS), specific frameworks and data nomenclatures. Our hypothesis is that, one first step to achieve robust reproducibility of sustainability assessments is the use of software agnostic tools. In contrast to data, software tools for LCA require specific knowledge on how to interact with the tools to achieve and reproduced the sought goals. There are different degrees of knowledge required: for programming-based tools, not only is it necessary to know how to program (or it's fundamentals) but it is also necessary to master the domain knowledge of the framework, and how it represents generic sustainability knowledge. For example, openLca proposes the creation of product systems to do LCA calculations, while other tools allow to simply use the processes, and other tools even use the concept of Activities or Nodes.

In our work, an early-stage Domain-Specific Language (DSL) prototype is introduced. It has the objective of enhancing reproducibility in sustainability assessments, particularly in building life-cycle inventories (LCI) and databases for life-cycle assessment (LCA). The prototype addresses the critical need for transparent data representation in LCA, tackling challenges in reproducibility and collaboration, without being locked to a single LCA tool framework. It is designed to facilitate transparent, reproducible sustainability evaluations, offering a framework for researchers and practitioners to analyse and compare studies. By distinguishing between data-centric challenges and reproducibility issues, the DSL aims to enable clear communication of LCA inventory creation as a first milestone towards improving reproducibility, with a clear separation between the software tool and the data. This separation from software intricacies provides a higher level of transparency, focusing on the steps taken to achieve LCA results rather than just the raw data.

The prototype, implemented in Python, involves designing a grammar for the DSL and an interpreter. The basic syntax includes elements for inventory creation, such as activities and exchanges.

The DSL prototype is in its early stages. It's current purpose is to lay the groundwork for future advancements in sustainability assessment methodologies. During the presentation, the different *challenges met in order to make the DSL useable with OpenLCA: usage of the IPC and jython interfaces, and concept mapping will be presented.*

7.7. A different way of mapping LCA elements, and why this is better

Andreas Ciroth

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Mapping of objects in LCA is a tedious, basic, and typically needed task when migrating data from one LCA reference system to another, or also when merging LCA data from different reference systems. The "classic" approach for mapping is to establish pairs which basically align one object in one of the reference systems to one object in the other reference system, for example one flow in ecoinvent to one flow in the LCA Commons. Sometimes, a notion of how well the mapping is is added, e.g. in UN GLAD (https://github.com/UNEP-Economy-Division/GLAD-ElementaryFlowResources/blob/master/Mapping/Output/Mapped_files/FEDEFLv1.0.3-ecoinventEFv3.7.xlsx). This is useful as quite often, the pairwise assignment is not perfect: there is more than one option on one side, a more or less detailed option only, or only a somewhat similar option. In an ongoing EU research project ENGINE, a data pool for sustainability is created somewhat differently: Existing LCA reference systems are brought into a polymorphic TypeQL graph database, which allows to "cast" given LCA data in one or the other reference systems, with an indication of quality. We believe this solution is more flexible and powerful than the pairwise mapping.

In the presentation, common issues in mapping will be summarized, the polymorphic database and the data model for the various LCA reference systems will be explained, and an example will be shown for a practical use of the database, for LCA Commons data. The presentation will conclude with a discussion, including the potential for making LCA data better.

7.8. Development of a standardized method for validating life cycle assessment data

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So far, LCA models cannot be fully empirically validated in reality. This hampers credibility of LCA results and makes the creation of trustworthy LCA models and of process datasets in LCA more complicated and lengthy than necessary. This presentation will present an approach for empirical reality check of LCA models and datasets. To perform this, LCA models will be broken down into individual aspects and elements, which are each candidate for a reality check of these. Methods include comparing LCI data with chemometrics or mass balance, with other data sources (satellite imagery, other case studies, PRTR data etc.). Satellite pictures can provide location-specific data on rainfall and soil moisture, which *can be used to predict the minimum irrigation requirements. The irrigation water values in LCA datasets should always exceed this predicted minimum. This example highlights how LCA data can be validated by comparing it with real-world, empirically derived estimates. The overall aim of my work is to identify and test empirical validation methods for Life Cycle Assessment (LCA)*

In the presentation I will summarize the reasons why LCA data may not fully correspond to reality, how to develop strategies to detect LCA data reality mismatches, and show some application examples of these strategies. The presentation will conclude with a discussion, including some challenges of validation and ways to reduce the gap between LCA and reality.

7.9. The GeoPolRisk Tool to develop Characterization Factors for Supply Risk of Abiotic Resources in Life Cycle Impact Assessment explained and illustrated with a CaseStudy

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Life cycle assessment, a comprehensive and standardized method to evaluate environmental impacts across a product's life cycle, traditionally focuses on "inside-out" impacts caused by the product on the environment, emphasizing resource use, global warming, and other environmental impacts. In contrast, the "outside-in" perspective considers resource availability and accessibility to industry. This second perspective has been developed as a way to integrate raw material criticality assessment into LCA. The GeoPolRisk method assesses the supply risk based on global production concentration, import shares, political stability scores, and the average price of the commodity. This presentation introduces the GeoPolRisk tool that includes a characterization model which allows to calculate the Geopolitical Supply Risk Potential of using 46 raw materials across different countries in multiple years. The characterization factors developed show the highest values for precious metals, like platinum group metals (PGMs), reflecting their high market prices and concentrated production in geopolitically unstable regions. The results emphasize the significance of spatial and temporal variations in characterization factors, providing a nuanced assessment of supply risk associated with the product system. Despite data limitations, the characterization factors offer a good estimate of the supply risk of raw materials available for use in product systems. A case study llustrates the application of the GeoPolRisk. From an "outside-in" perspective the case study demonstrates how the GeoPolRisk method complements traditional environmental indicators such as global warming, making it valuable tool for assessing mineral resource supply risk in Life Cycle Impact Assessment.

7.10. Including Microplastics in Life Cycle Impact Assessment

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Microplastics (MPs) represent a significant threat to biodiversity, with their presence documented across a wide range of ecosystems. Recognizing this, recent efforts have been made to integrate MPs impacts into life cycle impact assessment (LCIA), providing a more comprehensive understanding of the environmental impacts of products and services that emit MPs throughout their life cycle.

The MarILCA group, which aims to include the impacts of marine litter in LCA, has been at the forefront of these efforts. Initial developments included characterization factors (CFs) for microplastics in the marine environment, including a range of 5 different microplastics sizes (1 to 5000µm), 9 different polymers (EPS, PP, LDPE, HDPE, PS, PLA, PET, PVC and TRWP) and 3 different shapes (bead, film, and fiber). These CFs have now been updated to include additional compartments and ecosystems such as the sediments as well as freshwater ecosystems (lakes and rivers) and terrestrial ecosystems (agricultural and natural soil). Thus, a methodology has been developed to aggregate impacts across different environmental compartments and at different scales (continental and global), regionalized for 8 world regions.

Additionally, several polymers and natural fibers were added for a more comprehensive assessment (SPA, PU, PAN, starch blend, PBAT, PHA, PA, viscose, cotton, wool, and linen). CFs for MPs were computed for different units compatible with various LCIA methods: PDF·yr for GLAM, PDF·m^2·yr for Impact World+, and species·yr for ReCiPe. By applying these CFs to LCA case studies in sectors such as textiles, fishing, and food packaging, we demonstrated that MPs emissions throughout the product life cycle can have significant impacts and could influence LCA outcomes and decision-making in some cases.

Several limitations remain, such as uncertainties in fate modelling and data gaps for certain compartments and ecosystems. For example, biodegradation data specific to all compartments is lacking. This highlights the need for continued efforts to refine the existing models and expand coverage to additional MPs effects such as the ecotoxicity of additives. Ongoing work of the MarILCA group includes a detailed fragmentation and degradation model, and characterization of human health effects and of macroplastics impacts.

Therefore, this proposal highlights the latest developments and future directions of the MarILCA group, emphasizing the importance of including MPs impacts into LCIA for a more accurate and meaningful comparison of plastics and their alternatives to inform sustainable product design and policy-making.

8. Food and Agriculture

8.1. Assessment of the environmental impacts of EU broiler chicken production depending on the reduction of dietary protein-to-energy ratio and geographical origin of soybean

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The energy and protein requirements of modern broiler chickens are generally met throughout the provision of balanced commercial diets with optimal protein-to-energy ratios. The availability of EU soybean, the main protein source in poultry feeding, is a critical aspect being the amount of it not sufficient to meet domestic demand making the EU strongly dependent on imports from Latin America and the US. The present study aimed to quantify the environmental impacts of broiler meat production according to the crude protein-to-metabolizable energy ratio and the geographical origin of soybean. A total of 600 one-day-old male Ross 308 chicks (n=300/group) were fed a conventional basal diet (CON) or the same diet with a 10% lower crude protein content (LOW) using EU soybean. The birds were slaughtered at 34 days age (body weight: 2,429 ± 54 g) and LCA was applied to assess the environmental implications according to the tested experimental factors. Acidification (AP) and eutrophication (EP) potentials were assessed using the CML-IA baseline method, while the global warming potential (GWP) was calculated through the ReCiPe 2016 midpoint (H) method. The analysis was conducted on a cradle-to-farm gate basis considering the functional unit (FU) = 1 kg of live brid weight (LW) and on a cradle-to-plant gate basis when the FU was 1 kg of breast meat (BM). Then, two scenarios were hypothesized comparing soybean imported from Brazil (#1) or US (#2). The use of CON or LOW diets and EU soybean did not affect the selected impact categories at farm gate. Otherwise, the use of LOW diet slightly increased (+5/14%) the impact categories when BM was considered. Independently of FU, scenario #1 consisted in an increase of +24/30% of GWP and +15/26% of the AP, whereas a reduction (-10/15%) was observed for the EP. However, in case of utilization of US soybean, an increase of all impact categories was detected both for CON and LOW diets and FUs (GWP: +10/17%; AP: +42/52%; EP: +6/12%). In conclusion, the reduction of crude protein-to-energy ratio did not influence the considered impact categories at farm gate, while worsened the environmental impacts for 1 kg of BM at plant gate. Overall, the use of EU soybean represents the most environmentally sustainable choice for EU broiler meat production; indeed, the import of soybean from overseas results in an increase of GWP and AP impact categories.

8.2. Assessing the environmental impacts of small-scale biobased technologies in the African context through LCA: The case of BIO4AFRICA Project

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In recent decades, the global community has engaged in the development of sustainable and circular biobased solutions to facilitate a shift towards environmental sustainability. These solutions are particularly relevant for the Global South, where local socioeconomic externalities render native societies vulnerable to the effects of current environmental threats. In Africa, additional detrimental factors are present; Political instability, overexploitation of natural resources, the expected population boom, and the observed environmental burden-shifting on Africa's natural sinks, further degrade African societies' defenses against such threats.

To this end, research related to the development of such solutions tailored for Africa currently receives considerable funding from the European Union. The BIO4AFRICA project (GA 101000762) is a H2020 project, aiming at a gender-balanced diversification of revenue in rural Africa, through the promotion of circular, sustainable, and replicable biobased solutions. In total, five biobased solutions—Green Biorefinery, Pyrolysis, Densification, Hydrothermal Carbonization, and bioplastics/biocomposites—are being tested across four African pilots (Uganda, Ghana, Côte d'Ivoire, and Senegal), in a variety of potential applications (e.g. production of animal feeds, solid cooking fuel) that mitigate local deficiencies. Overall, the innovative nature of these solutions promises environmental improvements and important socioeconomic benefits through tailor-made value chains and small-scale compatibility.

Among the key tasks of BIO4AFRICA, the environmental sustainability of the project's solutions is assessed through LCA. These studies are conducted not only as stand-alone assessments of the solutions' environmental performance, but also for direct comparisons with conventional counterpart practices and products (e.g., conventional animal feeds, conventional cooking fuel). For these studies, the OpenLCA software along with the EcoInvent database have been used.

Among the LCA studies conducted, the Ugandan Green Biorefinery study shows promising outcomes. This solution utilizes locally available green biomass to produce animal feeds with high protein availability through a series of mechanical and physicochemical processing stages. The respective LCA results highlight that most environmental impacts occur during the biomass cultivation phase due to fertilizer use. Alternative fertilization methods, such as intercropping and manure application, were included in the LCA scope, showing potential for environmental impact reduction. Additionally, comparative LCA studies between the solution's products and conventional animal feed (soybean meal) highlight the environmental superiority of the solution's products when intercropping or mixed fertilizing practices are applied. As for the Senegalese combined application of Pyrolysis/Densification to produce biochar briquettes as solid cooking fuel, the LCA results show promising environmental performance against the conventional Senegalese cooking fuel mix.

8.3. Environmental Impact Analysis of Crop Residue Burning in Madhya Pradesh: A Multivariate Comparison across Key Crops

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This study quantified the environmental impacts of residue burning of major produced and burned crops in Madhya Pradesh, central India. The environmental impacts were quantified using Life Cycle Assessment (LCA) coupled with monte Carlo simulation of 1000 iterations. Crop wise marginal impacts of the crops have been quantified using Multivariate regression model. The results showed sugarcane and rice have the highest emissions in key impact categories, such as particulate matter formation (PMF) and global warming potential (GWP), whereas wheat and maize exhibit comparatively lower impacts. The combustion of residues significantly increases marine eutrophication (MEUT), agricultural land use (ALU), terrestrial acidification (TEAF) and global warming potential (GWP). Each kilogram of burned residue results in an increase MEUT by 21%, ALU by 0.05%, TEAF by 0.046% and GWP by 0.028%, intensifying climate change. The results underscore the immediate necessity for specialized residue management strategies for sugarcane and rice crops. It is advisable to utilize sustainable alternatives such as composting or biochar production to mitigate emissions and enhance soil health, thereby addressing environmental and human health issues.

8.4. Optimizing Meat Packaging: Integrating Shelf-Life Modeling into OpenLCA for Sustainable Packaging of Perishable Foods

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This study introduces an innovative approach to integrating shelf-life and consumer behavior into OpenLCA, using a case study that compares modified atmosphere packaging (MAP) and plain wrapping paper for minced meat. The objective was to quantify the environmental impacts of "over- and under-packing" relative to the shelf life of perishable foods. By integrating shelf-life data into LCA calculations, the study aimed to assess the environmental impacts associated with packaging-related food losses when the shelf life is exceeded. A consumer survey was conducted to develop a log-normal distribution reflecting consumption patterns of MAP and plain wrapped paper, which assigns probabilities to specific days for meat consumption, allowing for the adjustment of environmental impacts accordingly.

The packaging system studied includes a polypropylene (PP) tray with a low-density polyethylene (LDPE) multilayer film, varying in tray thickness, gas composition, and ethylene vinyl alcohol (EVOH) content in the lid film. Results showed that the tray significantly contributes to environmental impacts across all categories, unlike MAP and LDPE film, which have minimal contributions. Increasing tray thickness results in higher environmental impacts, whereas reducing thickness shortens shelf life, leading to increased impacts due to potential food losses. A shorter shelf life necessitates increased meat production to meet the functional unit: "environmental impact per 500 g of minced meat sold and packaged expected to be consumed within the modeled shelf life." Thus, less packaging does not

necessarily equate to fewer environmental impacts. The study found that wrapping paper is a more sustainable option if the consumption pattern meets the shorter shelf life of plain wrapped paper compared to MAP packed minced meat. Overall, meat production has a significant influence on environmental impacts, considering shelf life and consumer behavior. Depending on the individual consumption behaviour, consumers may prefer MAP packed food to avoid environmental impacts from food losses.

The study highlights the importance of optimizing packaging not just for its material and design, but also for its ability to protect the food inside, e.g. extend product shelf life and minimize food waste, thus reducing the overall environmental footprint. This integrated approach offers valuable insights for developing more sustainable packaging solutions in the food industry.

8.5. Open Source LCA Toolbox for Seafood

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Blue foods, which are farmed or fished in marine or freshwater environments, supply around 3.2 billion people with their primary protein and generate livelihoods for around 800 million people. Blue foods have the potential to supply the world with low-carbon emission proteins and play an essential role in the shift towards sustainable food systems that are aligned with the planetary boundaries. However, as fisheries and aquaculture operations are tremendously diverse, with around 3,000 species being fished or farmed, conducting robust and reliable Life Cycle Assessments (LCAs) is complex. This is especially true because LCA practitioners are often unfamiliar with the seafood industry, while involved seafood industry stakeholders may not be aware of the data needed to conduct a robust LCA. Currently, there are no easy-to-use tools or templates that define the necessary parameters for seafood LCAs and facilitate data gathering for fishery or aquaculture operations.

To bridge this gap, Blueyou Impact, in collaboration with LCA experts, has developed a comprehensive guideline and easy-to-use data gathering templates for LCAs in the seafood industry. The toolkit defines all important parameters required for a robust LCA of fishery and aquaculture products and provides clear guidance for seafood stakeholders and LCA practitioners on how to integrate the data into LCA models. Blueyou's LCA toolbox eliminates the need to start from scratch for every seafood LCA! The ready-to-use templates empower anyone to immediately begin gathering comprehensive data for fisheries, aquaculture, and processing operations. This approach significantly enhances operational efficiency on a global scale and optimizes resource utilization in every seafood Life Cycle Assessment (LCA) conducted worldwide.

8.6. Waste to Wealth: Leveraging openLCA for Policy and Practice in Urban Farming Through Optimized Composting

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The intertwined challenges of urban waste management and food security necessitate innovative, interdisciplinary strategies that bridge scientific research and policy implementation. This study investigates the transformative potential of openLCA, a life cycle assessment (LCA) platform, in optimizing compost formulations tailored for urban household farming. A meticulously designed compost mix—comprising 10% banana peels, 10% orange peels, 10% papaya peels, 10% mango peels, 20% food waste, 20% brown materials, and 20% green materials—was developed to enhance nutrient recycling, reduce waste, and boost agricultural productivity in aquaponic systems. The study integrates advanced statistical tools, including Design of Experiments (DOE), ANOVA, T-tests, and SPSS, to ensure robust, data-driven optimization of compost quality. Results were further analyzed using openLCA to evaluate environmental, economic, and social impacts, focusing on key metrics such as greenhouse gas reduction, resource efficiency, waste diversion, and cost-effectiveness. Case studies demonstrate the adaptability and scalability of the compost formulation across diverse urban contexts, highlighting its role in aquaponic systems to boost productivity and promote nutrient recycling while advancing circular economy principles. This interdisciplinary work bridges the gap between science and policy, creating a collaborative framework for policymakers, scientists, and stakeholders. It facilitates knowledge exchange, fosters innovation, and provides actionable strategies for scaling up compost-based urban farming solutions. By leveraging stakeholder feedback and LCA-driven insights, the study underscores the transformative potential of organic waste valorization to achieve food security, environmental resilience, and socioeconomic development. The findings establish a precedent for integrating sustainable waste management and urban agriculture into policy frameworks, setting the stage for global sustainability transformation.

Keywords:

Urban Waste Management, Food Security, openLCA, Compost Optimization, Aquaponic Systems, Greenhouse Gas Emission Reduction, Circular Economy, Policy Integration, Statistical Analysis, Sustainable Agriculture, Socioeconomic Development, Stakeholder Collaboration, Knowledge Exchange, Global Sustainability Transformation.

8.7. The importance of infrastructure within LCA of microalgae production and processing facilities

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Whilst Life Cycle Assessment (LCA) of microalgae has grown substantially within the literature, with significant detailed work on a whole range of production, harvesting, and processing techniques, modelling often needs to include more consideration of infrastructure. For the past ten years, our LCA group has been working on producing a range of infrastructure models for our LCA of microalgae facilities, which have supported decision-making processes within the design. We present here the findings from the LCA of the preliminary designs for the REALM Horizon Europe microalgae system, which is a circular economy approach linking agriculture, microalgae production, and aquaculture. The systems include greenhouses for food production, raceway-based microalgae facilities, production of bioactive materials, and aquaculture food production systems. The LCA covers the infrastructure impacts and eventual disposal of the facility after a lifetime of thirty years and uses assumed productivities to estimate hypothetical minimum impacts for the microalgae. Stainless steel is one of

the main contributors in the construction of new downstream processes, while the PBR material, which can vary from glass to PMMA, can be significant upstream. The infrastructure is usually neglected mainly due to the long life of the materials and high microalgae yearly production, but it can still be significant, especially in a new industry under development such as the microalgae sector; therefore, its impacts should be assessed. In addition, end-of-life scenarios are important, especially for materials such as GRP, for which new recycling technologies are currently being developed and, in theory, would be industry standard by the time current microalgae facilities are decommissioned.

9. Alternative Materials

9.1. Life Cycle Assessment of an Innovative Composite Utility Pole: Environmental Benefits of Replacing Creosote-Treated Wood

Miss Helen Brown

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This study presents a comparative Life Cycle Assessment (LCA) of an innovative composite utility pole technology developed by Pollywood Ltd against traditional creosote-impregnated Scots Pine poles. The assessment follows ISO 14040/44 standards, using openLCA 1.9.0 with the Ecoinvent 3.6 database and ReCiPe 2016 impact assessment methodology. The functional unit was defined as one meter of utility pole, with a cradle-to-gate system boundary.

Results demonstrate the Pollywood system achieves significant environmental improvements across multiple impact categories. Most notably, the Global Warming Potential (GWP) of the Pollywood pole is less than 10% of the traditional creosoted pole, primarily due to the elimination of toxic creosote treatment. The innovative design, utilizing European Silver Birch with polyol and diphenylmethane diisocyanate, not only reduces environmental impacts but also addresses key industry challenges including:

- *Elimination of carcinogenic creosote exposure*
- *Improved material efficiency through multiple poles per tree*
- *Reduced weight for easier installation*
- *Lower toxicity across freshwater, marine, and terrestrial impact categories*

While based on preliminary manufacturing data, this study suggests that Pollywood's technology represents a significant advancement in sustainable utility pole production, offering a viable path to reducing the environmental footprint of power distribution infrastructure.

9.2. Ocean Water-Driven Microbial Cellulose for Sustainable Biomanufacturing

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Cellulose, an abundant biopolymer, is essential for numerous industries spanning textiles, biomedicine, and packaging applications due to its structural properties and renewability. However, traditional

cellulose production, derived from cotton sources, faces significant environmental challenges, including high freshwater consumption, extensive land use, and reliance on synthetic chemicals. This study introduces a sustainable method for cellulose production by utilizing ocean water as a growth medium for Komagataeibacter xylinus, a microorganism capable of producing bacterial cellulose efficiently under optimized conditions.

Techno-economic assessments were first conducted to evaluate the feasibility and scalability of this approach. Results demonstrated that ocean water-based bacterial cellulose production significantly reduces costs by eliminating the need for freshwater and agricultural inputs, offering a sustainable alternative aligned with global environmental goals. The method also retains the superior material properties of bacterial cellulose, such as high purity, tunable structure, and compatibility with diverse applications, including biomedical, packaging, and environmental uses.

Building on the techno-economic results, a Life Cycle Assessment (LCA) was performed to quantify the environmental impacts of bacterial cellulose production. Using a detailed process inventory and advanced Life Cycle Impact Assessment (LCIA) modeling, the LCA evaluated multiple impact categories, including water consumption, energy use, and land use. Optimized production conditions achieved significant reductions in water consumption—14.29% and 31.25% per functional unit (1 kg of cellulose and 1 kg of cellulose per unit of tensile strength, respectively)—compared to conventional cotton-based cellulose. These results demonstrate the potential of bacterial cellulose to address water-use inefficiencies, particularly in regions facing freshwater scarcity.

This study integrates techno-economic analysis with advanced LCIA modeling to provide a robust framework for assessing the sustainability of innovative biomanufacturing processes. By leveraging ocean water, this method mitigates regional environmental pressures, supports resource conservation, and reduces competition for freshwater. Additionally, the incorporation of regionalized LCIA modeling advances the understanding of the environmental impacts of cellulose production systems.

These findings highlight the transformative potential of ocean-water-based bacterial cellulose production as a scalable, cost-effective, and environmentally sustainable alternative to conventional methods. This research advances LCIA methodologies while addressing critical global sustainability challenges, offering a pathway for innovation in industrial biotechnology and biopolymer production.

9.3. Algae in Action: Life Cycle Assessment of Brilliant Planet's Carbon Capture system

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To reduce the impacts of anthropogenic climate change, we need to rapidly decarbonise, and also remove the CO_2 society has emitted and continues to emit into the atmosphere. One suggested method to do this is by growing, drying and burying microalgae. Brilliant Planet has worked for the past six years on developing a microalgae-based process to undertake carbon capture and storage from the ecosystem. Currently, the company has an operational three-hectare pilot facility based in Akhfennir, Morocco. An independent ISO 14040/44 compliant Life Cycle Assessment (which has considered the operational and infrastructure-based impacts) was undertaken for a 3-phase project consisting of a demonstrator, commercial and full-scale facility, using data from an existing three-hectare pilot site, in *order to understand if the Brilliant Planet System (BPS) is a true carbon sink. This study shows that when using low-carbon electricity, the full-scale facility has the potential to sequester carbon with an efficiency of 93% (70 $kgCO_2$ emitted per 1000 $kgCO_2$ sequestered); hence, over a lifetime of 30 years, the system could sequester 3.8x106 tCO_2. Based on this, the Brilliant Planet System is a useful technology that can contribute to a global strategy to slow anthropogenic climate change.*

9.4. Life Cycle Analysis of Continuous Glucose Meter: Evaluating Environmental Impact and Circular Strategies for Reduction of Resources Used and Carbon Emission

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Diabetes has been declared a public health emergency, with 537 million people experiencing this condition worldwide. Diabetic-supporting devices, including meters, are a lifeline for people with diabetes, providing critical monitoring and control of blood sugar. Conventional glucose meters require blood samples via finger multiple times a day. Continuous glucose monitors are more recent technology that measures blood sugar levels regularly throughout the day from interstitial fluid beneath the skin.

Despite advancing diabetes care, continuous glucose sensors have raised environmental concerns because they are single-use and contain significant material resource. A typical glucose meter set includes packaging, an applicator, a sensor unit, and a transmitter for logging data to a smartphone, all disposed of every 10-14 days. The environmental concerns around these monitors led to the recent international Green Diabetes Summit (2021) exploring ways to reduce the impact of diabetes technology, goals which align with UK and European goals to make healthcare services 'carbon net zero'.

In this study, we explore the potential to reduce the environmental impact of diabetes monitors through design and materials changes, informed by environmental analyses to identify 'hotspots'. Accordingly, we conducted a cradle-to-gate life cycle analysis (LCA), combined with materials flow analysis (MFA), of a diabetes set widely used in the UK (Freestyle Libre 3, Abbott). We used OpenLCA with the EcoInvent database (v3.9.1) to model and quantify carbon emissions during typical usage. MFA determined the material resource used at each of the life cycle stages.

We explored two scenarios; firstly a baseline demonstrates current practice in which all the parts are disposed of every two weeks. The second scenario uses circular economy strategies; demonstrates the impact if design changes are conducted to enable re-use of the applicator and transmitter, thus prolonging their lifetime and opening new opportunities for end-of-life recycling. This aligns with the narrowing (reducing the materials), slowing (reusing), and closing (recycling) material loops. Outcomes demonstrated that modest changes to design and use can bring significant reductions in carbon equivalent emissions and resource use in comparison to baseline.

In conclusion, this study presents a pragmatic approach combining LCA and MFA to assess the extent to which proposing design changes can reduce carbon emissions and resources used. The results highlight the potential to use circular economy-based strategies to inform and guide the design and healthcare policy of glucose meters.

Keywords: Medical device, glucose meter, circular economy approach, material resource, sustainability, healthcare industry.

10. Renewable Fuels and Energy Systems

10.1. Environmental impact assessment of the R&D progress of a conceptually designed malic acid biorefinery

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A malic acid biomanufacturing plant utilizing methanol as feedstock is conceptually designed [1]. The novel process is based on fermentative production of malic acid followed by purification via reactive extraction requiring various organic solvents with diverse environmental impacts. A hypothetical strain of Bacillus methanolicus, which can produce malic acid from methanol with a titer of 65-100 g/L is used as the biocatalyst. Metabolic engineering and process development progress can maximize product concentration as well as methanol utilization efficiency while minimizing CO2 evolution. R&D effort towards these goals requires Pareto-optimal resource allocation. Two environmental impact metrics; namely, global warming potential and water use are used for multi-objective optimization along with other techno-economic criteria. Two cases are considered: a base case where minimal R&D progress is assumed and a best case where all objectives are met with 100% success [2]. Optimal scenarios are identified between these two limits. Pareto-optimal allocation of limited R&D resources facilitates a trade-off between mutually-conflicting environmental and techno-economic objectives.

The biomanufacturing process is modelled and simulated by Superpro Designer. The calculation of the environmental impact metrics is performed by OpenLCA software with ReCiPe 2016 Midpoint (H) methodology and the ELCD Database. Optimization is conducted using MATLAB.

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10.2. Primary Environmental Impacts Assessment on a Dual-Fuel Power Plant Using Producer Gas and Diesel Fuel Mixture

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This study aims to determine the principal environmental implications of a 3-6 kW power plant generated using a dual-fuel engine based on palm kernel shell gasification. The analysis encompasses a gate-to-gate assessment that includes the palm kernel shell gasification process, gas cleaning system, and electricity generation. Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP), and Ozone Depletion (OD) as the environmental impacts of the power plant operation are reviewed using the Environmental Footprint Secondary database. It is noted that the GWP, EP, and OD indicators for all loads are influenced by diesel fuel consumption, which is the largest contributor to emissions.

The analysis indicates that operating diesel engines at a low load has a greater environmental impact, contributing more significantly to global warming potential, acidification potential, eutrophication potential, and ozone depletion. This is demonstrated through an impact analysis conducted using openLCA v2.3 software, comparing the emission impacts at 3 kW and 5 kW. At a load of 3 kW, the global warming potential (GWP) is 77.49 kg CO2-eq/kWh, compared to 30.63 kg CO2-eq/kWh for a load of 5 kW. Similarly, the acidification potential (AP) is 11.3 x 10^{-2} mol H+-eq/kWh versus 3.6 x 10^{-2} mol H+-eq/kWh, the eutrophication potential (EP) is 21.91 × 10^{-4} kg P-eq/kWh versus 9.18 × 10^{-4} kg P-eq/kWh, and the ozone depletion (OD) is 35.54 × 10^{-9} kg CFC-eq/kWh versus 14.94 × 10^{-9} kg CFC-eq/kWh.

The main contributor to emissions at each load is the series of processes involved in the conversion of the actual biomass carried from the process in the plantation until it enters the palm kernel shell gasification, which results in a much higher environmental impact compared to fossil fuels, especially at lower loads. However, this is considered carbon neutral and part of the short carbon cycle.

Operating a diesel engine at a high load is more advantageous because it produces a lower primary environmental impact. When the engine runs at higher loads, it typically achieves higher efficiency, and less fuel is consumed per unit of power generated. Furthermore, it will reduce fuel costs and lower emissions of harmful pollutants, including carbon dioxide and particulate matter.

10.3. Comparison of Different End-of-Life Modelling Approaches for an Environmental Life Cycle Assessment of Agrivoltaic Systems in Austria

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Agrivoltaics (APV), which is the parallel use of agricultural land for both food/feed and electricity production through photovoltaic (PV) modules, is an important research area due to its potential to enhance land use efficiency. In a previous study by the authors, the environmental impacts of two APV systems were evaluated using the Life Cycle Assessment (LCA) method and compared with the impacts of using the land solely for agriculture or solely for electricity production with PV modules (common ground-mounted PV plant). To ensure a fair comparison, a system expansion approach was employed to account for both agricultural products and electricity outputs. Previously, the system boundaries were limited to a cradle-to-gate analysis. The current focus is on incorporating the end-of-life (EoL) phase into the LCA to provide a comprehensive assessment. The proposed study aims to compare different EoL approaches for the assessed multi-output product system, building on the cradle-to-gate system expansion approach already applied. Specifically, the study evaluates a stilted (S-) and a vertical

bifacial (VB-) APV system. The following four EoL modelling approaches are assessed: cut-off approach with allocation by classification (CO), avoided burden (AB) approach, open-loop with closed-loop recycling procedure with expanded system boundaries (OL) and the Circular Footprint Formula (CFF). For recycling input and rate European averages are used. The functional unit is set to 1 kWh of electricity and a basket of agricultural goods. As software openLCA v2.1.1 with ecoinvent database v3.8 and ReCiPe 2016 Midpoint (H) impact assessment method is used. Highest environmental impacts are found when applying the CO approach in all the impact categories. In the climate change impact category impact reductions compared to the associated impact with the CO approach of 16% (S-APV) and 4% (VB-APV) are identified with OL, 10% (S-APV) and 7% (VB-APV) with AB and 22% (S-APV) and 19% (VB-APV) with CFF. The study reveals notable variations in the results due to the four evaluated EoL methods. The CO approach, though easy in handling, lacks recycling incentives. The AB approach is also easy in handling, and promotes a high recycling rate at the EoL. The OL approach promotes higher recycling input and substitution of high-impact virgin materials. The CFF approach, despite being less practical, mirrors market conditions and incentivizes either increased recycling input or rate. Given these findings, we suggest that the ISO 14044 recommendation for sensitivity analysis should also extend to EoL approaches.

11. Advancing LCI

11.1. Importance of Uncertainty Modeling in LCA for robust Environmental Performance Classification Ranking - the case of Avoided Impact of ICT Services

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At the moment the momentum is high for trying to use LCA for expansion of energy rating style classification of product and services to include absolute environmental performance credentials. Initiatives such as Emissions thresholds, Green Claims Directive and the Battery Regulation classification of batteries into carbon footprint performance classes are part of this, as well as Energy Label classifications for laptops. Moreover, PCR and PSR development in standardization organizations such as IEC and ETSI fit this trend and naturally the content side of the DPP.

Another emerging area is avoided impact calculations methodologies for electronics systems and specific digital services. Consumers making purchasing decisions for digital services will respond to simple and understandable information, which can be aggregated to a single metric, score or class. Such scores might be based on LCA. However, the uncertainty methodologies in the current LCA standards are not prescriptive enough. Recently an attempt in ETSI has been done to standardize the uncertainty and sensitivity calculation for avoided impact LCA calculations and beyond. If the absolute uncertainty of the final score is not quantified in a uniform manner, beyond the data quality rating semi-quantitative approaches, it will be challenging to understand the usefulness of the LCA result.

Products and services might use similar or different methodologies for determining the appropriate performance classes.

The uncertainty range of current environmental performance classifications is generally not evident. Moreover, the reusability of the energy label classification method for LCA based classification is not clear due to a certain lack of trust in the LCA scores.

Here is presented LCAs for various ICT enabling Services, which all include transparent uncertainty assessment, and the corresponding relation to various performance class methodologies. It is clear that the uncertainty must be limited (likely by PSR) if LCAs for ICT Services enabling potential (and other simpler applications) are to be used as basis for performance classification.

11.2. Developing a Life Cycle Inventory for a future large accelerator facility

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The ISIS-II Neutron and Muon Source, proposed as the successor to the ISIS Neutron and Muon Source at the Rutherford Appleton Laboratory in the UK, presents a unique opportunity to evaluate environmental impacts during a large accelerator facility's early feasibility and design stages. By identifying potential impacts at this stage, environmental sustainability strategies for impact reduction and mitigation can be integrated into the design process.

A pioneering simplified Life Cycle Assessment (LCA) of the entire facility was conducted using OpenLCA software, the ecoinvent allocation cut-off by classification model and unit process database, and the ReCiPE 2016 midpoint (H) Life Cycle Impact Assessment (LCIA) methodology. Developing the Life Cycle Inventory (LCI) for such a complex and nascent project was a significant challenge, given the vast array of infrastructure, subsystems, components, and parts—many without prior LCAs. This presentation will discuss the strategies employed, modelling approaches, assumptions made, and uncertainties evaluated to construct a workable LCI for this first-of-its-kind LCA, which has provided critical insights into the environmental implications of design choices for a future large accelerator facility.

11.3. Applying openLCA's advanced features to increase transparency and reliability of secondary plastics EcoProfiles

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Plastics are ubiquitous materials in modern society, offering versatile mechanical properties and broad applicability, from general uses such as packaging to specialized applications like electronic components. Despite their benefits, the pervasive use of plastics and their reliance on fossil-based supply chains have driven a growing demand for transparent information on their environmental performance. Since 1993, PlasticsEurope has provided EcoProfiles - comprehensive life cycle data for European production of chemicals/plastics - widely adopted in the life cycle community and various databases. However, these profiles lack transparency, offering only aggregated data and focusing solely on the production of primary polymers. To overcome these limitations, we established a methodology for generating transparent life cycle inventory (LCI) and life cycle impact assessment (LCIA) data for secondary plastics production using the advanced features of openLCA.

In collaboration with PlasticsRecyclersEurope and the PRIMUS project, the collected primary data was integrated in openLCA 2.3 to model recycling processes on a per-site basis. Individual recycling processes were aggregated into representative European production models, weighted by the production capacity and multi-output share of each site. These models utilized global parameters to facilitate process creation and data averaging, validated through a comprehensive sensitivity analysis. Combination with other database approaches, e.g. the plastic littering risk approach from the PLEX database, allowed us to close data gaps for the formation of particulate matter and microplastics.

After focusing on the generation of detailed LCI results, openLCA has also enabled the export of data in ILCD and JSON-LD formats, increasing transparency and usability for the life cycle community. To supplement the newly published LCIA data for gauging sustainability performance within the industry, *the provision of semi-aggregated datasets will facilitate both further hotspot analysis and custom scenario analysis of these datasets. Furthermore, to contextualise the LCI and LCIA results, we employed a comprehensive data quality approach utilising Ecoinvent's Data Quality System to estimate data uncertainties. Applying the integrated Monte-Carlo-Simulation feature of openLCA allowed to create, for the first time, quantified uncertainty values for LCI and LCIA results for EcoProfiles.*

Our research has demonstrated the value that openLCA can provide for the generation of transparent and high-quality life cycle inventories and impact assessments. Its advanced features, such as integrating heterogeneous model data and performing Monte Carlo simulations, enable more accurate and reliable environmental evaluations. This highlights openLCA's potential to support sustainable plastics production and recycling processes through improved data transparency and uncertainty management.

12. Posters- Advancing LCIA

12.1. Advancing Life Cycle Impact Assessment: Exploring Normalization and Weighting Methods in Single-Score Analysis of a District Cooling Plant [ID 47]

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District cooling plants are becoming increasingly important as they play a key role in providing energy efficient and sustainable urban cooling solutions when climate change drives temperature increases globally. Single-score results in LCIA can enable effective communication and decision making. The aim of this study is to investigate the effects of different normalization and weighting methods, applied to the case study of the district cooling plant "Wien Schottenring," in Vienna, Austria.

At the time of data collection, the plant had a cooling capacity of 19.8 MW_{th} and operated a combination of three compression chillers and two absorption chillers. The compression chillers were powered by grid electricity, while the absorption chillers used predominantly district heat as their energy source. A time-resolved modelling approach is used to analyze electricity and district heat supplies as well as the cooling demand, taking into account time variations in energy flows and consumption. Operating data was provided by the operating utility, Wien Energie GmbH. LCA results will be compared for two cooling variants:

Variant 1 (existing configuration): Cooling with both absorption and compression chillers.

Variant 2 (alternative configuration): Cooling with compression chillers only.

Various normalization and weighting methods will be applied to arrive at single-score LCIA results. These include ReCiPe, EF 3.1, the ecological scarcity method, and alternative normalization approaches from recent literature. Finally, a normalization based on national Austrian data will be applied to account for regional specificities.

The robustness of the comparison between the two variants will be evaluated with regard to the choice of normalization and weighting approaches and to the resulting single-score results. Also, the contributions of individual categories to the single score will be analyzed, both for uniformly weighted normalization methods and for weighting methods (ReCiPe and EF). Finally, we will show the effect of applying a regionalized Austrian normalization set compared to the global and EU-wide normalization sets.

The study ***will apply a range of*** *normalization and weighting methods to one of the future key technologies for urban climate change adaptation. Single-score LCA results can easily be* *communicated to non-experts, making a careful analysis of the underlying methods critical to providing robust decision support for industry and policymakers.*

12.2. Towards a Comprehensive, Comparable and User-Friendly Water Footprint: Advancing the Integration of Water Quality into Water Footprint Assessments [ID 64]

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The provision of clean water represents one of the most urgent global challenges – today and in the future. To mitigate the risks of water scarcity and associated social conflicts, a more sustainable approach to water management is essential. As part of sustainable water management strategies, it is necessary to implement robust and meaningful indicators to evaluate and optimize water use. Water footprints can serve as such indicators, but still have some shortcomings.

While water scarcity is well-addressed in existing water footprint methodologies (e.g., AWARE or WAVE+ models), the assessment of water quality remains inadequate. Current water quality models lack comprehensiveness (focusing only on the most harmful parameter), are limited by insufficient comparability (absence of predefined parameters), and poor usability (requiring measurement of numerous parameters).

The main objective of this study is to address these gaps by developing a comprehensive water quality model and integrating it with an existing water scarcity footprint framework. A predefined set of quality parameters is provided to ensure comparability and usability. They are selected based on literature, legislation and expert consultations.

The combined model enables a more holistic representation of water quality and scarcity impacts. It provides a robust tool for assessing the sustainability of water management practices across various scales, including regions, municipalities, businesses, and products. Furthermore, the approach is designed to be compatible with organizational, regulatory, and political frameworks, enabling its adoption in many sustainability contexts.

This work was supported by the German Federal Ministry of Education and Research (BMBF) as part of the Thuringian Water Innovation Cluster (ThWIC) under the WatAs project (03ZU1214PB).

12.3. Harmonizing Life Cycle Assessments of Delivery Drones – Consistency and Standardizing Metrics [ID 70]

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LCA results heavily depend on the LCI, with the mobility sector being no exception to the rule. Particularly in studies which assess potentials for future mobility solutions, modeling assumptions, system boundaries and the LCI data can strongly influence the LCA outcomes. However, data gaps in available publications impede an effective comparison between the different studies.

In the work performed, 23 studies on environmental assessments of delivery drones were systematically searched and analyzed. The review revealed substantially different results regarding delivery vehicles, drone components and life cycle phases with highest environmental impacts. An analysis of the studies indicated a strong dependance of the impact assessment results on the LCI. Key factors such as component weight shares and the inclusion of production phases were found to significantly influence relative calculated emissions. For example, studies with higher weight shares assigned to batteries in the LCI had the tendency to attribute higher environmental impact shares to the battery production. Studies focusing only on the use phase often deemed drone delivery as environmentally friendlier option, while those including production impacts mostly favored ground delivery.

In addition to these divergent conclusions, comparison was further impeded by data gaps, which lead to the exclusion of multiple studies from specific comparisons and hindered a broader comparability of the results. Moreover, inconsistent definitions of LCI, system boundaries and functional units further complicated obtaining harmonized findings across the different studies.

*To address these challenges, the presented study proposes a standardized functional unit, kg CO_2-eq/kg*km, which should facilitate consistent comparisons across LCA studies on delivery methods. By providing a common basis for future assessments, the proposed functional unit can help to close data gaps which otherwise impede comparison of environmental impacts.*

With this, the presented work emphasizes the need for systematic approaches for the LCI modeling and data reporting to improve comparability of results across LCA studies, and offsets, how different study assumptions can lead to diverse study outcomes for similar research questions. By identifying possible sources for differences in results and by proposing strategies for harmonization, this study can serve as a reference for better comparable and transparent LCAs of delivery drones. In a broader context, it can additionally emphasize the high importance of LCI assumptions and data reporting for future analysis of a study.

12.4. Completing the life cycle inventories of product carbon footprints: two case studies from the industry in Austria [ID 128]

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As global awareness of climate change intensifies, accurate accounting of greenhouse gas (GHG) emissions associated with products have become essential for enterprises. The authors aim to illustrate challenges mastered in two projects with different Austrian industrial companies. Although both companies differ in size and sector, they must meet specific requirements of individual customers with a wide range of product variants (make-to-order). These customers are increasingly demanding transparency regarding the products' GHG emissions.

The first case study deals with a company that develops, sells, and services test equipment. As this company considers itself an engineering service provider, and – depending on the definition – the life *cycle of a product starts with its development, the resource consumption of R&D activities should consequently be included in the product carbon footprint (PCF). Although the design is the main factor influencing a product's sustainability, little research has been done into the contribution of the product development process to emissions. Despite some difficulties with correct allocations, it became clear that in our case the material consumption of prototyping causes more GHG emissions than the energy consumption of years of computer-aided construction. But it has also been revealed that these environmental burdens are negligibly small compared with the footprint of the full life cycle ("cradle-to-grave").*

Also, in the second case – involving a manufacturer of cabinet systems for energy distribution – internal processes ("gate-to-gate") were inventoried with a level of detail that exceeds common practice. As part of the project, data sets of the enterprise resource planning such as bills of material, information on processing steps and times, facilities' energy consumption, and transports between plants were enhanced with emission factors. The result was a calculator tool enabling a semi-automated analysis of inventory data. A full PCF can be determined with few more inputs on distribution and use stage. By means of interpolation, almost the entire product portfolio, consisting of several thousands of variants, can be quantified. Furthermore, the datasets of all previously created PCFs are stored centrally. This database not only facilitates decent reporting at both the plant and corporate levels (especially concerning the hard-to-capture Scope 3 emissions), but also simplifies the evaluation of PCF evolution.

This work addresses the crucial role of comprehensive life cycle inventories (LCIs) to close data gaps and provide useful insights. Essential points of the two cases can be transferred to a systematic approach relying on business data and operating statistics to complete LCIs.

12.5. Addressing data quality in the selection of generic data to link the background system to the foreground system. [ID 151]

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As global industries decarbonise, new materials and technologies are emerging to support this transition. Life cycle assessments (LCA) can be broken into two systems: the foreground system, for which primary inventory data is collected, and the background system which encompasses the wider economy. The LCA modelling process is iterative and often requires multiple rounds of life cycle inventory (LCI) data collection and modelling. This includes the selection of generic background process to represent foreground materials. Generic LCI databases play a crucial role in LCA and the development of environmental product declarations (EPDs). However, choosing appropriate background data to represent novel foreground processes and materials, such as bio-based materials or new recycling processes, will likely become even more challenging. The new European standard, EN 15941, helps to support the choice of generic data for the production of construction EPDs. For example, it provides rules for reporting the data quality of the relevant generic data used in product LCAs.

In this work, we provide a new technique/framework for tracking the data quality of the specific selection of generic data during the LCA modelling process. This allows LCA modellers to manage the data quality of their background generic data selections and use the visual outputs to discuss with *manufacturers and other stakeholders. This transparency and open discussion about data quality and associated uncertainties in the modelling should aid discussions around the sensitivity and variability of early-stage LCA, where poor data could greatly affect the results. The new approach promotes targeted data quality monitoring at the crucial boundary between the background and foreground processes. We hope that integrating this background-to-foreground generic data quality monitoring into the early discussion for product LCAs will encourage manufacturers and stakeholders to investigate their wider supply chains leading to wider impacts beyond their own practices.*

13. Posters- Circular Economy

13.1. Hotspots identification in the avionic antenna industry from sustainability and circularity perspectives [ID 67]

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Sustainability and circularity in antenna manufacturing focus on reducing environmental impact by the following aspects: i) the use of eco-friendly materials, ii) energy-efficient stages, and iii) minimizing waste. In more detail, the EU's ongoing project NANOMAT has emerged as a great opportunity to promote the implementation of sustainable processes and materials together with the improvement of the circularity of the avionics antenna industry.

First, the researchers involved in the current assessment have explored the application of eco-design principles throughout the identification of the weakness of the nanoelectronics from an environmental point of view. Here, the following issues have been addressed in NANOMAT: i) energy equipment efficiency, ii) materials use (metals/chemicals), iii) operation efficiency, iv) consumable use and v) waste management. For instance, the manufacturing in a cleanroom facility enhances the quantification of the material consumption. Moreover, the optimization of the gas carrier consumption is also needed in the nanoelectronics industry to move towards a more sustainable industry. In this respect, the use of a close chamber may be useful to optimize this consumption avoiding gas leakages.

In addition to the application of eco-design principles, the researchers have scanned the implementation of circular KPIs to measure the circularity. In this connection, 58 circular indicators have been found. These indicators have been classified into the following categories in accordance with the main phase/phases associated with the product: i) taking resources, ii) making product, iii) using products and iv) recovering materials and energy.

Moreover, Life Cycle assessment and Life Cycle Costing has been implemented for the manufacturing of 1 batch of RF MEMS (one of the main elements of the antenna) to evaluate the sustainability from an environmental and economic perspective. Seven stages have been included in the manufacturing of this device in accordance with data from literature: i) wafer cleaning and test, ii) oxidation of wafer, iii) CPW metal layer patterning, iv) dielectric deposition and layer patterning, v) sacrificial layer deposition and patterning, vi) top layer deposition and patterning and vii) top layer release. For environmental evaluation, the top layer deposition and patterning stage has been found as the most critical one, since the gold consumption is the main driver associated with the environmental impacts derived from the RF MEMS manufacturing. On the other hand, oxidation of wafer has been identified as the highest cost driver resulting from the use of photoresists, which must be minimized.

13.2. Charting a Sustainable Future: Leveraging Circular Economy (CE) as the Map and Life Cycle Assessment (LCA) as the Compass to Navigate Environmental Challenges in the Apparel Industry [ID 111]

Ms. Mitsuyo Sugimoto

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In 2019, the United Nations Conference on Trade and Development highlighted that the apparel industry is regarded as "the second most environmentally polluting industry in the world." Amid growing concerns about fashion, driven by a linear economy, there is an increasing call for a transition to a circular economy. In this context, Circular Economy (CE) and Life Cycle Assessment (LCA) are complementary tools akin to a map and a compass. CE offers a broad framework of the industry's circularity, while LCA identifies the environmental impacts at each product lifecycle stage. By combining these approaches, more significant reductions in environmental impact can be achieved.

This session explores the integration of CE and LCA in the apparel industry, addressing two main challenges.

The first challenge is the diversity of raw materials used. Environmental burdens differ significantly between natural fibers and synthetic fibers. Additionally, including composite materials like plastic buttons and metal zippers complicates efforts to reduce, reuse, and recycle (3R).

The second challenge arises from the global nature of supply chains, where most garments are produced overseas. Tracking environmental impacts at every stage is tremendously tricky, making measuring the full environmental footprint challenging.

To address the first challenge, LCA can be utilized to identify environmental impacts across the entire supply chain. An ideal CE model can be developed by analyzing the environmental burden of natural and synthetic fibers and blended materials. Natural fibers tend to have lower end-of-life impacts but cause excessive water use and soil pollution from fertilizers, while synthetic fibers contribute to greenhouse gas emissions and waste accumulation. Additionally, blended materials complicate 3R efforts. These underscore the importance of "Design for the Environment (DfE)" considerations in the apparel industry.

To tackle the second challenge, the research examines how apparel manufacturers in Japan and the EU track and disclose supply chain environmental impacts. In both countries, there are still few apparel companies that disclose their environmental impacts. However, the hypothesis is that in the EU, LCA is integrated into CE policy through initiatives like the "Eco Design for Sustainable Products Regulation," "Digital Product Passports," and "EU Taxonomy," which systematically reduce environmental risks. In Japan, the CE strategy exists, with LCA using limited and environmental risk management primarily relying on industry self-regulation.

This session aims to provide insights into the integration of CE and LCA, enhance understanding of the challenges in the apparel industry, and propose strategies for a sustainable future.

13.3. Toward circular and sustainable wine supply chains: a social insight [ID 140]

Dr Bianca Maria Tragnone, Professor Ioannis Arzoumanidis, Professor Luigia Petti, Professor Alberto Simboli, Professor Andrea Raggi

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Nowadays, an increasing number of initiatives aims to promote the transition to a circular economy as an alternative to the current linear economic model. However, this transition does not necessarily result in sustainability: the research found that adopting a circular solution does not guarantee, per se, sustainability, which should be assessed on a case-by-case basis.

The CICULAGRIS project (Towards Circular and Sustainable Agri-food Systems: Metrics for Assessment) (Prot. 2022JNNJJX) investigates the debated correlation between circularity and sustainability through the identification and application of appropriate metrics to assess circularity and sustainability with the aim to understand whether and to what extent the adoption of circular practices in some crucial Italian agrifood-chains (i.e. wine, olive oil and bread/pasta) leads to an improvement in sustainability. The processes and activities associated with the circular practices identified in each supply chain will be evaluated by applying the circularity assessment methods and related indicators that emerged from a review of the existing literature on the topic. Then, a sustainability assessment will be performed by applying Life Cycle Assessment (LCA), Life Cycle Costing (LCC) and Social Life Cycle Assessment (S-LCA), with some necessary adaptations depending on data availability and supply chain-specific methodological challenges. Finally, the circularity and sustainability assessment results will be correlated to understand whether and in what terms the circular systems analysed are also sustainable.

This study will focus on the social issues associated with circular practices in the wine supply chain. Indeed, the transition to circular economy solutions has an influence on several stakeholders, both in a positive and negative way. However, in this context, social issues are still rarely taken into account. Therefore, indicators of social circularity in the wine sector will be identified through a systematic literature review. Then, the study will evaluate whether and how the identified indicators can be integrated within an S-LCA study.

Acknowledgement

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13.4. Towards Sustainable Plastics: A Life Cycle Assessment of PLA-based Biocomposites reinforced with Agave Bagasse Fiber versus Conventional Plastics. [ID 145]

MSc Gary Lara, PhD Martin Esteban González López, PhD Misael Sebastián Gradilla Hernandez, IBT Juan Daniel Castanier Rivas, MSc Anaid Lopez

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As global environmental challenges, including resource depletion, and climate change, intensify, the need for sustainable materials has never been more urgent. Conventional plastics, primarily derived from fossil fuels, significantly contribute to these issues due to their long decomposition times, carbon emissions during production, and widespread accumulation in ecosystems. In response, bioplastics—plastics made from renewable resources such as plant fibers and biodegradable polymers—are increasingly explored as a promising solution. Biocomposites, which combine renewable feedstocks such as plant fibers, straw, or wood, with biodegradable polymers like polylactic acid (PLA), represent an additional alternative that could reduce dependence on fossil resources and minimize environmental impacts. In this context, Agave bagasse fibers, a byproduct of Tequila production, have been identified as a potential feedstock for biocomposites production. Although reusing this solid waste presents a promising opportunity, it is crucial to assess its environmental performance thoroughly, considering the entire life cycle, from raw material extraction to end-of-life disposal. This study, therefore, focuses on the life cycle assessment (LCA) of PLA-based biocomposites reinforced with Agave bagasse fiber (PLA-AF), comparing them to conventional plastics like polyethylene (PE), low-density polyethylene (LDPE), and reference bioplastics such as PLA and polyhydroxybutyrate (PHB), all of which exhibit similar mechanical properties.

The study was conducted on the OpenLCA software v.2.1.1 where all ReCiPe mid-point environmental indicators including climate change, resource depletion, water consumption, and land use were assessed for each plastic. PLA-AF biocomposite proved to be a more eco-efficient option than PLA and PHB bioplastics, showing reductions between 8-45% across all indicators. However, both PE and LDPE demonstrated a lower environmental impact than the PLA-AF on most indicators, with reductions between 30-75%, except for fossil resource depletion, where it showed an increase of 23-34%. The greater impact of PLA-AF biocomposite versus conventional plastics was mainly due to the environmental costs associated with PLA production and the agave bagasse fiber chemical pretreatments required, as well as the standardized, widely adopted production processes for these fossil fuel-based plastics. Nevertheless, the environmental performance of PLA-AF could be further enhanced by incorporating green chemistry principles into biocomposite development. The context-specific nature of assessing the environmental impact of circular bioeconomy schemes is crucial, as they are not always inherently beneficial and must be considered in light of SDG 12: Responsible Consumption and Production.

14. Posters- Food And Agriculture

14.1. Environmental Impact of Feeding Regimes in Organic Dairy Farming: Comparative Life Cycle Assessments Across Systems and Scales [ID 27]

Dr. Amir Sahraei, Dr. Deise Knob, Johannes Eisert, Dr. Christian Lambertz, Prof. Lutz Breuer, Prof. Andreas Gattinger

Justus Liebig University Giessen, Gießen, Germany

This research investigates the environmental impact of varying feeding regimes within organic dairy farms, using Life Cycle Assessment (LCA) and the Cool Farm Tool. We present results from a controlled study at Gladbacherhof, the research farm of Justus Liebig University Giessen, and a broader ongoing analysis of 10 additional dairy farms in Germany.

The initial study conducted at Gladbacherhof examined high-input versus grassland-based, low-input feeding regimes using openLCA. Based on fat and protein corrected milk (FPCM) as the functional unit, the low-input regime showed higher environmental impacts across five categories (global warming, non-renewable energy use, land use, terrestrial acidification, and freshwater eutrophication), due to increased emissions from enteric fermentation, manure management, and feed production.

Expanding this work, a complementary study assessed greenhouse gas emissions from 10 additional organic dairy farms, five with a high-input and five with a low-input feeding regime. Using the Cool Farm Tool, this analysis found that on average, high-input farms emitted 0.93 kg CO_2-equivalent per kg of FPCM, whereas low-input farms emitted 1.23 kg CO_2-eq/kg FPCM. On a per-hectare basis, emissions were on average 7,857 kg CO_2-eq/ha and 5,929 kg CO_2-eq/ha for high- and low-input farms, respectively. To further refine these insights, a comprehensive openLCA analysis of the 10 farms is in progress.

Our findings highlight the need for emission-reducing innovations in organic systems, such as manure biogas production and renewable energy adoption, as well as for intensified research on emission factors in organic livestock. Further cross-farm collaboration, as promoted by the ClieNFarms and GreenDairy projects, can support the development and adoption of climate-friendly practices across diverse organic dairy systems.

14.2. A concept for including circularity in life cycle assessment of cattle farming systems [ID 48]

Johannes Zeidler, Dr. Stefanie Reith, Prof. Dr. Andreas Gattinger, Prof. Dr. Lutz Breuer, Dr. Lisa Petzoldt

Justus-Liebig-Universität, Gießen, Germany

Agriculture and especially animal farming systems are situated in a tradeoff between a growing demand for animal-based food like meat, eggs and milk on the one hand and an increasing concern about the detrimental effects animal farming can have on the environment on the other hand. Intensive systems with higher yields mostly perform better from a climatic point of view. Nevertheless, these systems are often highly dependent on feed from arable land. Therefore, they compete with direct human food cultivation. Circular cattle farming systems would reduce feed-food competition by feeding animals with by-products from the human food industry, from permanent grassland and side products from a healthy crop rotation like clover grass. A circular cattle farming system would recycle nutrients in a large percentage, offer ecosystem services while producing additional animal-based food for human consumption under high animal welfare standards.

In this context, the newly established research group ZirKUH will conduct sustainable performance calculation (SPC) using the Regionalwertleistungsrechnung and life cycle assessment (LCA) of cattle farming systems in Hesse, focusing on circularity. The objective of ZirKUH is to identify key impact hotspots, evaluate strategies for mitigation of environmental impacts, elaborate further circularity aspects and offer recommendations for sustainable farming practices.

As an overall goal, ZirKUH aims to strengthen the regional value chain for milk and beef, while establishing the scientific concept of circular animal husbandry systems within a regional context. In a first step, a status quo analysis of cattle farming systems in Hesse using SPC and openLCA will be conducted. In a second step, the assessments will be adjusted to profoundly represent and evaluate circularity aspects in cattle farming systems. This could either be done by choosing an alternative allocation method taking ecosystem services into account, or by implementing new impact categories, that picture circularity. The assessment will be done from cradle to farm gate using fat and protein corrected milk (FPCM) [kg], meat [kg] and area [ha] as functional units.

After a trial period in 2024, we will start data collection in the beginning of 2025. The goal is to assess approximately 50 cattle farms in Hesse, both organic and conventional. We will present our network and working structure, and how circularity aspects will be linked or implemented in LCA and SPC. First results of the status quo analysis using openLCA will be shown.

14.3. Life cycle assessment of different feeding strategies for dual-purpose breeds in organic chicken husbandry using insect meal [ID 61]

Dr. Uwe Häußermann, Dr. Petra Engel, Prof. Dr. Andreas Gattinger, Prof. Dr. Lutz Breuer

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The supply of methionine and cysteine for chicken is limited in organic livestock farming when domestic grain legumes are the only protein supply. As supplementation with chemically synthesized proteins is not permitted in organic animal husbandry, an overall high protein intake is required to meet the demand. However, the production of feed for monogastric animals an food for humans can compete. By developing circular feeding strategies, this competition can be reduced. For this purpose, the black soldier fly (Hermetia illucens L.) can be used as a natural supplement and feeding component.

This study aims at assessing the environmental impact by conducting a lifecycle analysis (LCA) of organic chicken husbandry with 1 kg of marketable eggs as functional unit. For these, three different *chicken breeds, including 2 dual-purpose breeds were kept in mobile housing systems at two different feeding regimes (with/without insect meal).*

The investigated system covers the life cycle for the laying phase. Impact categories are considered, for which it is known a priori that animal husbandry has a major impact: greenhouse gas GHG emission, air quality, eutrophication, N-efficiency and land use. Allocation is carried out using physical allocation. The LCA is calculated using openLCA 2.2 with experimental data on performance and feeding as well as database values from Ecoinvent v3.11 and literature.

The control group received the pullet ration, the pre-layer feed and the layer feed consisting of the components wheat, pea, an organic feed supplement suitable for the developmental stage, soya oil, feed lime and table salt. In the group fed with insect meal, 15% of the respective supplementary feed was replaced by insect meal, mineral feed was supplemented, and the remaining components were divided in their proportions so that both, control group and insect group, received the same amount of nutrients.

Layers in the control group had a lower performance with 172 eggs/shortened laying performance (SLPT) test than in the insect group with 186 eggs/SLPT. The feed requirement was higher in the control group with 26.8 kg/SLPT compared to I with 25.2 kg/shortened laying performance test. The feed conversion ratio (kg feed/kg egg mass produced) was therefore also higher in the control group with 2.60 than in the insect group with 2.23.

The present LCA study will be complemented based on data collected from exact trials, also taking other variants into account, as well as the LCA of chicken meat production.

14.4. Mycoprotein: relative and absolute life-cycle assessment for early-stage optimization of a novel food product [ID 88]

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The global food production system is accountable for a significant share of the environmental impacts. Population growth and increasing per capita meat consumption are driving the demand of meat products, responsible for the majority of food-related impacts. Alternative proteins increasingly emerge as a potential meat replacement to slow down this trend. In this study, we adopted a multi-disciplinary approach to develop a novel protein-rich food product with improved environmental performance. Through genetic engineering of a Yarrowia lipolytica strain, we obtained a food prototype based on the yeast biomass, commonly known under the commercial name of "mycoprotein". The experimental results formed the background to design a scaled-up plant producing mycoprotein at competitive commercial scale, using the process engineering software SuperPro Designer. Simulation results were used to formulate the cradle-to-gate inventory of the mycoprotein. A cradle-to-grave life cycle assessment, performed in the openLCA software, compared the environmental performance of mycoprotein and the largest consumed land-based meat. Montecarlo simulation enabled to assess the uncertainty of the results and formulate strategies to drive the optimization of the food prototype. Lastly, the study included an absolute sustainability perspective through the planetary boundaries framework, analyzing current transgression levels and formulating alternative dietary scenarios with improved environmental profile.

14.5. Prospective and context-based LCA: finding suitable circular economy strategies for biobased side and waste streams in Pirkanmaa, Finland. [ID 126]

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The potential of European bio-based side- and waste streams is not fully utilized. Due to a lack of commercialisation, residual biomass is often not valorised effectively. Therefore, conventional treatment pathways cause preventable environmental impacts.

The EU-funded Horizon project TREASoURcE aims at facilitating the establishment of new treatment pathways through the deployment of an electronic marketplace (EM) for producers and consumers of biomass.

This life cycle assessments (LCA) study assesses the potential benefit of an EM by establishing more circular bio-economic pathways in Finish municipalities by 2040. A focus is on biogas and biomethane production, which are widely discussed as promising treatment pathways of bio-based side- and waste streams.

Assessing the future impact of economic activities is a challenge for the conventional LCA methodology. Furthermore, LCA studies typically do not take the context of studied value chains into account, leading to unfeasible recommendations.

As the establishment of new valorisation pathways have long-term effects, a prospective LCA (pLCA) approach was chosen. pLCA studies require additional assumptions about future macroeconomic developments. For this, Integrated Assessment Models (IAMs) were introduced, which feature different economic developments scenarios. The premise database was used to make the IAM scenarios accessible.

Furthermore, this case study features selected context-based and regionalized properties of the case study region of Pirkanmaa and its municipalities, respectively. As part of the TREASoURcE project, this case study is based on farm level data collection by project partners in Finland.

This case study is one of the first studies that utilizes the openLCA software to include context-based indicators in a pLCA study, and thereby lays groundwork for EM policy recommendations for European regions and municipalities.

14.6. Combining qualitative interviews with quantitative LCA results to improve the sustainability assessment of carp (Cyprinus carpio) [ID 141]

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The Competence Center for Nutrition (KErn) deals, among other things, with products of protected geographical origin. The goals of EU protection of origin within the framework of the EU's Farm to Fork strategy are to strengthen the legal framework for geographical indications and to incorporate specific *sustainability criteria. As part of the "Sustainability Analysis of Protected Bavarian Specialties" project, all protected Bavarian specialties were reviewed regarding national and international sustainability goals. Qualitative interviews were carried out between January 1, 2021 and December 31, 2024. The aim of the project was to analyse all specialties and identify starting points for how they can contribute to achieving the sustainability goals. It was also intended to show how more sustainability can be anchored in the value chain of Bavarian specialties. It was shown that the specialties often score in the 2nd and 3rd pillars of sustainability (economic and social dimension) and have short transport routes through processing directly in the region of origin. They also contribute to the conservation of particularly valuable cultural landscapes and biodiversity. In this context, the carp (Cyprinus carpio) deserves special attention. It is not only a well-known Bavarian specialty, but as a native freshwater fish it is also important for the implementation of the Planetary Health Diet recommendations. In this article, we present the results of the qualitative sustainability assessment and compare and supplement them with quantitative results from Live Cycle Analysis (LCA) to achieve a more comprehensive assessment and to be able to provide more targeted recommendations for a more sustainable production.*

14.7. Comparative Environmental Assessment of Protected vs. Open-Field Agriculture: a case study of blueberry production [ID 144]

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The agricultural sector faces increasing pressure to meet global food demands while minimizing environmental impacts. Protected agriculture (PA), characterized by controlled environments such as high-tunnels, has gained attention for its potential to improve yields and has raised concerns about its environmental impact due to the massive use of plastics. In comparison, traditional open-field (OF) systems are claimed to have fewer environmental impacts. However, studies on the environmental impacts of these systems remain scarce, especially in developing countries. To address this gap, this study aims to assess a comprehensive comparison of eco-efficiency between PA and OO blueberry production systems in Jalisco, Mexico, a region known for its significant contribution to the national blueberry market.

A life cycle assessment (LCA) was conducted to estimate environmental impacts using a cradle-to-gate approach aligned with ISO-14040-2020. The life cycle inventory was developed with context-specific information directly from a local company, while background data was taken from the ecoinvent 3.9.1 database. The LCA was performed using openLCA 2.1.1 software and the ReCiPe 2016 midpoint (H) methodology. A sensitivity and an uncertainty analysis were included to assess the robustness and quality of the results. In addition, a novel hectare-equivalent (ha_e) approach is used to normalize environmental impacts across systems with different yields. It bridges a critical gap by allowing a direct comparison of systems with different yields, offering valuable insights for high-yield crops, where traditional per-hectare comparisons can overlook the sustainability of protected agriculture models.

The results reveal that PA systems exhibit a 28% lower global warming potential, emitting 4,328 kg CO2-eq per ha_e compared to 5,991 kg CO2-eq per ha_e for OF systems. PA also shows significant reductions in terrestrial ecotoxicity (63%), freshwater ecotoxicity (79%), and marine ecotoxicity (71%).

Although PA requires higher input for high tunnels, such as steel and plastic, this model offers greater environmental benefits due to increased production and also reduced pesticide and fertilizer applications.

The findings demonstrate that PA is a sustainable solution for blueberry production, optimizing resources and reducing environmental impact, particularly in regions with limited land and water. Despite challenges such as high costs and energy dependence, PA offers a scalable approach to balance productivity and sustainability, supporting global food demands and promoting sustainable agriculture in developing economies.

15. Posters- openLCA in Industry and Tools

15.1. LCA and sustainability reporting in the manufacturing Sector: a research case study towards an integrated web-tool [ID 72]

Ph.D Giorgio Cantino[1,2], Dr. Sara Gransinigh[1,2], Dr. Luca Monteleone[1,2]

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Introduction

With stricter European regulations towards sustainable production systems, industries increasingly need user-friendly solutions to streamline reporting. There is growing interest in tools integrated with existing management systems to merge LCA with sustainability reporting results.

This article presents a research case-study of the Italian branch of an international manufacturing company. Following carbon footprint studies at both product and organizational levels, the company seeks to implement a tailored solution to speed up sustainability accounting. The discussion will cover possibilities, and development progresses towards a web-tool.

Methodology

Various alternatives were explored to integrate a web-tool within Company's systems. There were assessed solutions to integrate sustainability-related data, LCA-calculation engine, back-end environment as well as front-end interface into a unique tool.

This was implemented on a Linux server by using Django 5.0, a Python web-framework, that expedited the development of a prototype based on a parameterized LCA model.

To connect openLCA's computation engine and databases via API, the Docker container 'gdt-server' was employed, ensuring a controlled and secure environment for non-technical users and offering custom solutions. The openLCA database was connected to the web-app using the library 'olca-ipc REST', providing calculation and LCA-data recovery functionalities. Using the 'olca-schema', there were assigned types to the web-app data to enhance code-control.

Calculation results were stored in PostgreSQL, an open-source object-relational system that enhances storage capacity and data relationships. This database also served as the back-end for user-entered data, enabling the processing of data and results' history. Additional front-end toolkits (e.g., Bootstrap) managed graphical visualization, and JavaScript files were used to make the web page interactive. Finally, Python scripts were modified to integrate user-modified data and perform calculations with adjusted parameters.

Results and discussion

The prototype facilitated data collection from various sources, calculations and visualization of sustainability and LCA results, enabling the export of printable reports. Its streamlined data-input made sustainability assessments accessible to non-technical users. PostgreSQL consolidated sustainability information into a single platform, providing near real-time updates. Its modular design eases future for easy replication and customization.

However, methods for visualizing results are still limited. Further research is needed to improve the identification of data classes, to be stored in the database to streamline data-collection.

Conclusion

The tool shown to the Company that tailored solutions could speed up calculations for sustainability reporting. Further developments will allow to integrate other type of data, as well as to connect to an LCA collaborative server, allowing multi-user LCA modelling.

15.2. Sustainability in train structures: An approach for life cycle assessment of new material combinations [ID 93]

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The future of rail transport and mobility is characterised by the requirements of passengers, manufacturers, operators as well as the political environment. The DLR project Rolling Stock (RoSto) develops innovative technologies for the design of next-generation railway vehicles to fulfil the diverse requirements of different stakeholders. While the focus is on user-oriented interiors, safety concepts, and improved aerodynamics, the use of resource-efficient and sustainable materials is an important aspect for the design of structures that should not be neglected. Although rail transportation is nowadays regarded as comparatively environmentally beneficial compared to alternatives such as automobiles and airplanes, their components are made almost exclusively from energy intensive and non-renewable, only partially recyclable, materials. Therefore, the design of new elements in the RoSto project is supported by Life Cycle Assessment (LCA) as an established method for calculating potential environmental impacts of products over their complete life cycle. This concept is exemplarily shown here for the design of a future rail vehicle's generic roof structure, establishing eco-design principles supported by LCA already in the early development phase. Among the list of potential materials are different types of wood, metals, and fibre reinforced polymers (FRP). From LCA perspective, today's challenge lies in the scattered nature of the available Life Cycle Inventory (LCI) data for such materials. However, many material systems differ considerably in their raw materials and production pathways and therefore need to be modelled with a higher level of detail to enable a fair comparison. The initial focus is on the use of different polymer systems within the roof structure. For this purpose, the application of three different resins is tested on its potential environmental effects and the results are then compared with each other as part of a parameter study. Additionally, background data sets from two databases available in OpenLCA, Ecoinvent and cm.chemicals, are analysed within this study and checked for any deviations and their implications on comparability. With the help of a sensitivity analysis and using the Environmental Footprint 3.1 impact assessment method., the results are placed in a comprehensive context in order to make future recommendations for the procedure of further investigations. This study is modelled in OpenLCA 2.3.1.

16. Posters- Renewable Energy Systems and Storage

16.1. LCA of Energy Communities with Renewable Energy Integration: Comparing Vanadium Redox Flow and Li-Ion Batteries [ID 41]

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Background and Purpose

Energy communities can make a significant contribution to a shift to renewable energy sources. Energy storage plays a central role in balancing the inherent volatility of renewables. This study examines the environmental impacts of a small energy community with electricity from the grid and from photovoltaics (PV), and with heat from district heat. Three variants were analyzed for their environmental impacts regarding electricity storage: one using a vanadium redox flow battery (VRFB), one using a lithium-ion battery (LIB), and one without any electricity storage.

Methods

For the variants a LCA was conducted using the software OpenLCA v1.11, with the ecoinvent database v.3.9.1. This study examines the three test cases, using foreground data from the operators of the reference system wherever possible. Specific manufacturer data were available for the VRFBs, enabling a detailed analysis of this technology. The functional unit for the analysis is 1 kWh of a mixed supply of electricity and heat as provided by the reference system. This ensures that the results are directly applicable to the investigated energy community. The impact of battery lifespan and efficiency is analyzed through sensitivity analyses.

Results

The results show that integrating battery storage systems (VRFB and LIB) leads to higher environmental impacts than no electricity storage, with a GWP reduction - compared to VRFB - of 40% achievable without storage, and a 25% reduction with a LIB. For the VRFB variants, vanadium pentoxide and upstream processes cause significant environmental burdens, especially in the categories of carcinogenic human toxicity and mineral resource scarcity. In terms of carcinogenic human toxicity, the results with VRFB are 94% higher than without a battery and 92% higher than with a LIB. A sensitivity analysis indicates that impacts in these two categories can be substantially reduced if longer battery lifespans are assumed. Supplementary electricity from the grid is the climate change hotspot for all variants.

Conclusions

The LCA helps to understand the environmental effects of different electricity storage options in the context of diversified renewable energy communities. The results indicate that the impacts of electricity storage may not always be beneficial. A life-cycle based approach can assist in the design of sustainable energy communities by considering a selection of environmentally friendly and operationally efficient energy generation and storage technologies.

16.2. Integrated life cycle assessment for evaluating different Modern Methods of Constructing emergency shelters for mitigation and resilience [ID 50]

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As natural and man-made disasters become increasingly frequent and severe, the demand for effective post-disaster emergency shelters has surged. These shelters play a critical role in mitigating disaster risks and enhancing community resilience, offering displaced individuals safety and security during crises. Despite their importance, current shelter solutions often fail to meet essential standards due to high costs, extended construction times, limited local involvement, and significant environmental impacts. Modern Methods of Construction (MMC), particularly modular systems, hold promise for addressing these challenges, yet their adoption in post-disaster contexts remains limited, especially in developing regions.

This study employs an integrated approach to assess the feasibility of three MMC technologies—3D printing (3DP), prefabricated systems, and container-based shelters—using a combination of Life Cycle Assessment (LCA), Life Cycle Costing (LCC), and energy performance analysis through Integrated Environmental Solutions Virtual Environment (IESVE). The study aims to provide decision-makers—planners, contractors, and construction professionals—with actionable insights to enhance post-disaster reconstruction practices.

Southern Syria serves as a case study due to its protracted post-war recovery period (2011–2020), which revealed critical shortcomings in emergency shelter provisions. Results indicate that container shelters outperform other methods in terms of embodied energy and life cycle costs, making them the most sustainable option within this context. By contrast, 3DP shelters demonstrate higher embodied energy (6.26% and 13% more than prefabricated and container shelters, respectively), elevated carbon emissions (43.6% and 43% higher), and significantly greater life cycle costs (43% and 77.58% higher). These findings underscore the technological and material inefficiencies associated with 3DP shelters, highlighting the necessity for advancements to reduce their environmental and financial burdens.

The study underscores the urgent need for further research to optimize materials and methods used in MMC emergency shelters, ensuring cost-effectiveness and sustainability. The implications of this research extend globally, addressing the critical issue of post-disaster housing for millions of displaced individuals and refugees. By advancing our understanding of MMC technologies, this study contributes to the development of more resilient and environmentally responsible shelter solutions, essential for future disaster response and recovery efforts.

16.3. Assessing peak renewable energy storage using co-electrolysis and methanation by LCA and Müller et al.’s CCU guidelines [ID 54]

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A consensus is forming in the scientific community: Carbon Capture & Utilisation (CCU) will be needed for a net-zero emission economy in the future; however, the technology will likely remain expensive. Therefore, applications shall be diligently selected. Due to importance of the technology and the inherent multi-functionality of the product system the topic early-on sparked interest in the LCA community. Müller et al., published guidelines on how to perform LCA on CCU technologies [1]. Although, the work has a high citation count a very limited number of studies use the guidelines on LCA case studies.

Therefore, our work set out to apply the guidelines on a 1 MW demo plant of a co solid oxide electrolysis cell with subsequent methanation producing synthetic natural gas from CO_2. Life cycle inventory data was obtained from a chemical process simulation performed in ASPEN. Different CO_2-sources such as fossil fuels (gas, coal), steel & cement production as well as waste incineration were analysed in the LCA’s scenarios. To answer various research questions different scenarios were investigated.

The best case, entailing an almost fully defossilised energy mix, showed clear advantages compared to the status quo. The current Austrian electricity supply was not enough to achieve environmental benefits. To complement those expected results an energy profile of a wind farm in Eastern Austria was analysed to find timeframes over the course of a year with surplus production, which could be used for the CCU plant as start-up times are short. Therefore, the research question, whether CCU plants, only makes sense in the future could be answered on the grounds of our analysis.

[1] *Müller, L. J., Kätelhön, A., Bachmann, M., Zimmermann, A., Sternberg, A., & Bardow, A. (2020). A guideline for life cycle assessment of carbon capture and utilization. Frontiers in Energy Research, 8,*

16.4. Life Cycle Assessment of Emerging Zinc-Based Battery Technologies: Hot-Spot Analysis, Challenges and Comparison with Lithium-Ion Batteries [ID 63]

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Energy storage systems are essential for the transition to climate-neutral energy systems, with batteries serving a key role in this transformation. However, current lithium-ion battery technologies rely on scarce materials, which not only pose supply chain challenges but also exhibit high potential environmental impacts. This highlights the need for alternative solutions based on more abundant environmentally friendly resources. Zinc-based batteries, which are already widely used in primary battery applications, therefore present a promising alternative for post-lithium-ion technologies in rechargeable systems.

This study explores the environmental impacts of two promising zinc-based battery technologies, zinc-air and zinc-manganese batteries, by conducting a Life Cycle Assessment (LCA). To date, research on LCAs of zinc-based secondary battery systems remains limited, particularly regarding manganese-based and oxygen-electrode-based solutions. Existing studies rarely address the upscaling of laboratory processes to industrial applications, nor do they compare different component variants with the aim of guiding the development of more sustainable battery solutions.

The aim of the conducted LCAs is to determine present hot-spots and provide assistance in deciding between possible alternative material or synthesis routes and thus contribute to minimizing the environmental impact of the batteries already in the development phase. Each technology is characterized by distinct battery components, whose roles and environmental impacts are analyzed within the LCA. The analysis covers the entire life cycle of the battery cells, including raw material acquisition and recycling at the End-Of-Life. To assess the feasibility of these technologies as realistic alternatives to state-of-the-art lithium-ion batteries (LIBs), the results are benchmarked against established LIB technologies. The study addresses methodological challenges inherent in comparing well-established LIB systems with emerging zinc-based alternatives, emphasizing the importance of robust assumptions to ensure fair comparisons showing the real potential of the assessed technologies.

The study confirms that zinc is not the environmental hot-spot of the cells. Instead, for zinc-air the potentially used coating for the zinc powder and the binder for the air electrode have the highest impacts in most of the assessed impact categories. For the Zinc Manganese battery, the impacts stem mainly from other components like the housing or current collectors. As the cells are not fully established, several assumptions, especially concerning the battery's performance, lead to uncertainties in the analysis, making the comparison to LIBs challenging.

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16.5. Life Cycle Assessment of green ammonia in Solid Oxide Fuel Cells for sustainable heat and power generation [ID 107]

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Green ammonia, produced from green hydrogen, can serve as a sustainable fuel and chemical feedstock. It can decarbonize different sectors such as agriculture, transportation, and power generation [1]. Furthermore, green ammonia, liquefied at moderate pressures, presents opportunities for large-scale energy storage and transport. Ammonia's potential as a fuel in high-temperature solid-oxide fuel cells (SOFCs) for electricity and thermal power generation is particularly promising. SOFCs can directly utilize ammonia as a fuel, eliminating the need for a separate hydrogen production step [2].

The present study aims to assess the environmental life cycle impact of an SOFC system fueled by green ammonia. The innovative system under consideration, developed within the Horizon Europe project AMON, includes the fuel cell (operating at temperatures in the range 650-750 °C), ammonia cracker, ammonia burner, and anode gas recirculation, as well as the whole balance of plant (BoP). The SOFC *employed is based on an 8kW G8x stack by SolydEra. Two main alternatives will be investigated: either including the external ammonia cracker or utilizing the internal cracking capability of the SOFC stack. The anode gas recirculation allows for enhancing net fuel utilization in the SOFC stack, reducing the amount of unreacted fuel and improving the overall electrical conversion efficiency.*

This study employs OpenLCA, following and complying with the LCA checklist developed by JRC, including international LCA standards ISO 14040 and ISO 14044, ILCD handbook and SH2E guidelines [3]. The environmental impacts are assessed across several key impact categories based on EF 3.1 methodology. The analysis integrates data from the Ecoinvent database, supplemented by operational and experimental data from the AMON project. The LCA focuses on cradle-to-gate boundaries, including the manufacturing and operation of SOFC stack and its associated balance of plant (BoP), with comparative analysis of the two configurations. By assessing the environmental impacts through LCA, this study provides insights into the sustainability of utilizing green ammonia in fuel cells.

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17. Posters- Social LCA

17.1. Comparative Lifecycle Assessment of Wooden and Concrete Buildings in Finland: Environmental and Socioeconomic Impacts [ID 83]

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The construction sector plays a pivotal role in global sustainability, influencing both environmental outcomes and socioeconomic dynamics. While discussions on sustainable construction often focus on environmental impacts, particularly carbon footprints, a more integrated approach is needed to address the full spectrum of sustainability. This study compares two identical multistorey buildings in Finland – one constructed primarily from wood and the other from concrete – by assessing environmental impacts through lifecycle assessment (LCA) and socioeconomic impacts using Social-LCA (S-LCA), and examining how these dimensions align and interact.

LCA evaluates environmental impacts beyond carbon footprint, covering each lifecycle stage from raw material extraction to end-of-life. By incorporating S-LCA, the study expands the assessment to include socioeconomic factors such as job creation and community benefits. This approach leverages LCA tools to explore the interplay between material choices and their environmental and social impacts.

Preliminary results suggest that the wooden building may have a lower environmental footprint, particularly due to reduced fossil energy demands. Socioeconomically, wood construction shows potential for supporting local job markets and rural economic stability. By addressing these interconnected impacts, this study contributes to more comprehensive sustainability assessments, offering insights that are particularly relevant for policymakers and industry stakeholders navigating material choices to achieve decarbonization and broader sustainability goals.

17.2. Social life cycle assessment of microbial and enzyme-based detergents [ID 134]

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Bio-based products are made from renewable biological resources and have the potential to address global challenges such as climate change, resource shortages, and environmental impacts. In addition to their promising possible environmental benefits, bio-based products could contribute to economic growth and social progress by improving efficiency, and generating job opportunities, further supporting sustainability claims.

Microbially produced and enzyme-based detergents as examples of bio-based products are the focus of this study. Using the Social Life Cycle Assessment (S-LCA) methodology, the social impacts of these enzyme-based products were evaluated. The methodology followed ISO 14075, UNEP/SETAC, and Handbook for Social Life Cycle Assessment guidelines, using OpenLCA software and the PSILCA database to assess two key social indicators: local employment and contribution to economic development. The results were analyzed through raw value and worker hour approaches for a complete understanding.

The analysis indicated that using bio-based detergents improved the sector's contribution to economic development in terms of GDP but slightly increased unemployment rates in raw value terms. On the other hand, the worker-hour-based approach revealed that bio-based detergents required fewer work hours throughout their life cycle—from raw material production to disposal—compared to conventional detergents. This reflects improved efficiency in resource use and reduced labor demands.

Overall, the study highlights that bio-based detergents can drive economic benefits and improve operational efficiency while promoting sustainability. However, the slight increase in unemployment rates underscores the importance of considering potential trade-offs in their social impacts relative to environmental gains. These findings emphasize the value of using comprehensive social assessment tools to evaluate the broader impacts of bio-based products.

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