ABSTRACT BOOK

SETAC EUROPE 26TH LCA SYMPOSIUM

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MAKING LCA MEANINGFUL: GOOD DATA, BETTER MODELS, SUSTAINABLE DECISIONS

Abstract Book

SETAC Europe 26th LCA Symposium

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This book compiles the abstracts from the 26th LCA Symposium of the Society of Environmental Toxicology and Chemistry – Europe (SETAC Europe), conducted from 21–23 October 2024 in Gothenburg, Sweden.

The abstracts are reproduced as submitted by the author and accepted by the programme committee. They appear in order of sessions and abstract code and per presentation type. The poster spotlight abstracts are included in the list of poster abstracts. The presenting author of each abstract is underscored.

The information in this abstract book reflects the status of the abstracts as was on 14 October 2024.

About SETAC

In the 1970s, no forum existed for interdisciplinary communication among environmental scientists, biologists, chemists, toxicologists, managers, engineers or others interested in environmental issues. The Society of Environmental Toxicology and Chemistry (SETAC) was founded in North America in 1979 to fill the void and quickly saw dynamic growth in the Society's membership, meeting attendance and publications.

A unique strength of SETAC is its commitment to balance the scientific interests of government, academia and business. The Society by-laws mandate equal representation from these three sectors for officers of the World Council and Geographic Unit Boards of Directors and Councils, and in the composition of committees and other society activities. The proportion of members from each of the three sectors has remained nearly equal over the years.

The Society is concerned about global environmental issues. Its members are committed to Environmental Quality Through Science®, timely and effective communication of research, and interactions among professionals so that enhanced knowledge and increased personal exchanges occur. Therefore, SETAC publishes two globally esteemed scientific journals and convenes annual meetings around the world, showcasing cutting-edge science in poster and platform presentations. Because of its multidisciplinary approach, the scope of the science of SETAC is broader in concept and application than that of many other societies.

SETAC's growth is reflected in the founding of Geographic Units around the world. SETAC Europe was established in 1989 as an independent organisation, followed by SETAC Asia-Pacific in 1997 and SETAC Latin America in 1999. In 2002, the four existing organisations joined together under the governance of the SETAC World Council. SETAC Africa is the most recent Geographic Unit, which was adopted in 2012. As evidence of international acceptance of the SETAC model and of the great interest at the local level, regional chapters and branches have emerged in a number of countries.

SETAC publishes two journals, Environmental Toxicology and Chemistry (ET&C) and Integrated Environmental Assessment and Management (IEAM). ET&C is dedicated to furthering scientific knowledge and disseminating information on environmental toxicology and chemistry, including the application of these sciences to risk assessment. Integrated Environmental Assessment and Management focuses on the application of science in environmental decision-making, regulation and management, including aspects of policy and law, and the development of scientifically sound approaches to environmental problem solving. Together, these journals provide a forum for professionals in academia, business, government and other segments of society involved in the use, protection and management of the environment for the enhancement of ecological health and human welfare.

SETAC books provide timely in-depth reviews and critical appraisals on scientific subjects relevant to understanding a wide range of contemporary topics pertaining to the environment. These include any aspect of environmental chemistry, toxicology, risk assessment, risk management or environmental policy. SETAC has two administrative offices, in Pensacola, Florida, USA, established in 1992, and in Brussels, Belgium, established in 1993.

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Track 1: Life Cycle Inventory

1.01 - Advances in Prospective Life Cycle Assessment

1.01.A.T-01 Modelling Dynamics in Prospective Life Cycle Assessment Towards Climate Neutrality

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The transformation towards climate neutrality induces dynamics in production processes and their value chain. Life cycle assessment of the global warming potential of transformation scenarios therefore requires a combined time differentiated prospective examination of foreground as well as of background inventories. Previous tools focussed on prospective background database modification. The state-of-the art Brightway package premise modifies ecoinvent systematically according to a specific scenario of a global integrated assessment model. This time consuming procedure is suitable for few time steps and scenarios. However, often foreground inventories need to be modified iteratively in order to test different technologies and transition paths of the production system in question. Consequently, the calculation of a life cycle inventory at each modification step of the dynamic foreground inventory leads to long computation times, limiting the practical implementation of previous approaches. The presented package Prosperdyn responds to this limitation by adding a dynamic inventory calculator to premise, which allows fast foreground scenario modifications separate from time consuming storing of large background databases. After one single import of background inventories modified via premise for each time step, subsequent scenarios are defined within one decoupled dynamic foreground database, which includes dynamics in every arbitrary process in flexible ways. After modification, this foreground database is relinked to the year specific background databases in a time-efficient way. This allows to consider all foreground flows in the actual year of their occurrence and to rearrange and calculate many different technology options iteratively. In combination with relative (global warming potential) and absolute (additional radiative forcing) climate metrics, Prosperdyn acts as a promising time-efficient tool to assess the effectiveness of various technology options in high temporal resolution as pathway towards a climate neutral future.

1.01.A.T-02 Addressing Parameter Uncertainty in Prospective Inventory Modeling

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Parameter uncertainty, arising from data gaps, inaccuracies, and non-representative data, poses a significant challenge in prospective life cycle assessment (pLCA). This type of uncertainty, widespread in life cycle inventory (LCI) data, remains a prominent challenge for pLCA practitioners. Although this is acknowledged, there is currently no standardized methodology to address parameter uncertainty within a prospective LCI framework. To fill this gap, our study offers a systematic approach to enhance the robustness and transparency of prospective LCI modeling by including uncertainties.

A guideline on selecting prospective methods for LCI modeling and approaches to characterize parameter uncertainty is presented. At first, modeling methods commonly used in pLCA are collected and grouped in clusters. Then, a systematic framework to model pLCI data based on findings from literature and our own experience is proposed. Afterwards, the clusters of methods are integrated into the systematic framework to aid the identification and characterization of parameter uncertainty. To demonstrate the applicability of our approach, an emerging energy technology example of a "fuel cell-based propulsion system for a hydrogen-powered aircraft in 2040"is provided.

Our guideline outlines a structured approach comprising six steps, which can be integrated into the established phases of life cycle assessment (LCA): "goal and scope definition" and "life cycle inventory". The first step involves defining the assessment's goal, scope, temporal boundaries, and considering the technology's maturity level. Step two focuses on collecting data to depict the development of the technology. Steps three through five specifically target parameters likely to undergo significant changes in the future, introducing uncertainties such as variations in manufacturing processes, materials, and component dimensions. Step six addresses external factors influencing the technology, adding uncertainties. The application of our framework to a solid oxide electrolyzer cell (SOEC) example allowed us to identify and characterize the most uncertain parameters affecting the technology's future development and adoption.

Our study provides a structured framework for mapping future technology development, encompassing various stages, critical factors, and inherent uncertainties. This guidance not only aids pLCA practitioners, but also contributes to more transparent and more consistent results.

1.01.A.T-03 Uncertainty Characterisation in Prospective LCA: Reliability of Pedigree Matrix Approach to Characterise Foreground Inputs' Uncertainty – A Case Study for Emerging Photovoltaics

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Life cycle assessment (LCA) is always associated with uncertainty. The uncertainty should be appropriately analysed in LCA to verify its influence on the impact results. To do that, several tools are available, such as global sensitivity analysis (GSA) supporting to identify the key parameters contributing to the uncertainty of the impact results. The accuracy of these uncertainty analysis depends on the reliability of inputs' uncertainty characterisation. However, in prospective LCA, usually there is not enough data to define the probability distribution of the input uncertainty. Pedigree matrix approach can support the characterisation of inputs distribution via data quality indicators with quite limited data information. As a practical and structured approach, the pedigree approach has been widely implemented in the LCA context, including in ecoinvent database. On the other hand, it has been criticized by several authors for its subjectivity and the lack of reliability, since its proposed uncertainty factors were based on experts' judgments or on the statistics of a limited number of data sources. The objective of this study is to compare and verify the reliability of the pedigree matrix approach in the prospective LCA by a case study of an emerging photovoltaics technology.

The pedigree matrix approach was compared with a benchmark approach generating parameters' distributions based on technical information and experts' knowledge. The pedigree matrix approach followed the methodology described in Bo Weidema's article and transferred different quality indicators of each parameter into lognormal distribution. Then GSA was applied twice in parallel, using one set of distributions for the foreground system parameters based on pedigree and another one based on the benchmark approach. The results of GSA were then compared.

The following trends were observed in the results: 1) The generated input distributions obtained by applying each of the approaches are partially different: the mean values of two sets of input distributions are close, but their proposed ranges are different for some parameters. 2) The identified key parameters from two approaches are the same in the majority of impact categories.

Although different input uncertainties may arise, the identified key parameters in GSA from pedigree matrix and benchmark approaches are the same for most of the impact categories. It can be considered that both of them are reliable, at least to some extent. Being a reliable and more practical approach, the pedigree matrix approach is recommended to be used for the characterisation of input uncertainty in the GSA of prospective LCA. This study verifies the reliability of the pedigree matrix approach in prospective LCA by a case study of emerging photovoltaics, contributing to increase the reliability and credibility of the results of prospective LCA.

1.01.A.T-04 Emerging Technologies in European Research: Enhancing Sustainable Engineering Practices & Data Collection for Life Cycle Assessments – A Case Study

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Introduction: Life Cycle Assessment (LCA) is increasingly integral to European research and development (R&D), reflecting a growing sustainability focus. In projects involving emerging technologies, early identification of environmental hotspots is crucial, shaping a product's environmental impact. However, acquiring pertinent data for these technologies presents persistent challenges.

Methods: Through a case study of the European research project MULTIMOLD, this investigation proposes an optimized project outline to address data collection challenges and enhance LCA practices for emerging technologies. Strategies include early involvement in the development process, enhancing environmental knowledge within the research consortium, conducting screening LCAs to pinpoint missing data and guide material selection, leveraging stakeholder expertise and networks, and streamlining data collection across various locations and institutions. Additionally, the iterative nature of prototype development presents opportunities to refine data collection and enhance environmental performance. These strategies improve the efficiency and effectiveness of primary data collection for prospective LCAs at the laboratory scale, facilitating more informed decision-making in sustainability assessments.

Results and Discussion: The investigation into data collection strategies within the MULTIMOLD project yielded significant findings. Screening LCAs conducted early on in the project enabled informed material and process selection, enhancing optimization efforts. Stakeholder expertise proved invaluable in identifying and evaluating potential proxy datasets, while stakeholder networks provided insights into industry processes and aided in obtaining and verifying industry data.

Conclusions: This paper highlights the persistent challenge of acquiring data for sustainability assessments and proposes strategies to optimize sustainable engineering practices and data collection processes for LCAs. Leveraging the iterative and interdisciplinary nature of European research projects, exemplified by MULTIMOLD, facilitates early involvement, enhanced environmental knowledge, stakeholder collaboration, and streamlined data collection. Integrating LCA throughout the project cycle enables real-time identification and mitigation of environmental hotspots, fostering proactive sustainability. These findings advance sustainable practices, informing decision-making in emerging technology development.

1.01.A.T-05 Systematic Technology Selection and Data Inventory in Lab-scale LCA: The Case of Perovskite Light-emitting Diodes

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Background and Purpose
The emergence of new technologies is driving recent advancements in future-oriented LCA. However, apart from the intricacies of modeling the future, another critical consideration is the selection of technologies among others at the lab scale (i.e., which technologies are promising for scaling up?). This study aims to introduce a systematic technology selection and subsequent data inventory preceding a lab-scale LCA for screening purposes. The rapidly expanding field of perovskite light-emitting diodes (PeLEDs) serves as a case, which lacks any known LCA study as of the writing of this abstract.

Methods
A series of workshops was conducted between researchers in sustainability assessment and material science at Linköping University. The objectives of these workshops were (i) to design a literature search and selection aimed at achieving comprehensive coverage of promising PeLED devices, and (ii) to collect material and energy input-output data, simulating similar laboratory synthesis conditions.

Results
Snowballing from Nature Portfolio journals published between 2018 and 2023, 18 PeLED devices were identified as promising based on four elicited selection criteria: external quantum efficiency, lifetime, brightness, and luminous power efficiency (LPE). LPE required derivation as it is not directly reported in literature but is deemed important for LCA. LPE measures the amount of power used to generate light or the electricity consumption during the use phase.

Inventory of data from the literature demands completeness and comparability—aspects which are not detailed in typical lab-scale LCA. Completeness necessitates deriving the amount of materials from the given concentration of reagents and thickness of different layers of PeLED devices, and the energy consumption from the time of use of every machine. Comparability requires adjusting effective material use based on stoichiometric relations and resulting device active area, knowing that the reported material proportions are not optimized for material efficiency.

Conclusion
Interdisciplinary collaboration is essential for a systematic technology selection and subsequent data inventory. This contribution extends beyond the common narrow lab-scale LCAs assessing only one or a few new technologies, instead providing a comprehensive selection aimed at guiding further technological developments in consideration of promising technologies from broad technology pool.

1.01.B.T-06 Prospective LCA of three German Transformation Scenarios Achieving Climate Neutrality by 2050

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Background and Purpose
On behalf of the German Federal Environment Agency, the REFINE project is investigating the environmental impacts of the transition to a climate-neutral and resource-efficient society. Switching to renewable energy leads to considerable savings in greenhouse gases and other combustion-related emissions. At the same time, it will require significant infrastructure change and expansion. REFINE is investigating potential environmental side-effects. How will the demand for raw materials in Germany change? What is the relationship between the greenhouse gas emissions saved domestically and those caused abroad by the German energy transition? These questions are addressed by a newly developed prospective life cycle assessment (pLCA) model.

Methods
In collaboration with ecoinvent, a pLCA model has been developed that depicts three transformation pathways for the years 2020 to 2050. To adapt the ecoinvent database, about 3,000 datasets and 70,000 parameters per scenario and year were modified or added. Particular attention was paid to renewable electricity generation plants, synthetic fuel production technologies, heat pumps, energy storage and alternative drive systems. In addition, recycling rates, electricity mixes and heat generation were changed throughout the database, new industrial processes (e.g. DRI steel, Celitement binder) were introduced and efficiency developments were incorporated. The databases were transferred to Brightway, where the LCA calculations and analyses were carried out. The differentiated final energy demand for Germany resulting from the scenario studies served as a functional unit in the LCA calculation.

Results
The impact of domestic greenhouse gas emissions falls by 96-99% by 2050 in the scenarios analysed, while the impact of imports from abroad falls by at least 84%. Most other environmental impacts and resource demands also decrease, but not as much as global warming potential. However, in one scenario, land use and cumulative energy demand in 2050 return to 2020 levels due to the production of electricity-based synthetic fuels. Demand for metallic raw materials rises sharply in all scenarios as a result of defossilisation.

Conclusions
A comprehensive pLCA model has been developed that maps the global development for three transformation scenarios. It allows the assessment of possible environmental impacts depending on the future energy demand in Germany. Detailed analyses and sensitivities can be performed.

1.01.B.T-07 Will the Environmental Impacts of Green Hydrogen be a Matter of Choice? – A Prospective Life Cycle Assessment of a Large-Scale Proton Exchange Membrane Water Electrolysis Plant

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Hydrogen is anticipated to be a central pillar of the economic transition. In order to reach that goal, a rapid scale up of the currently commercially available small-scale water electrolysis plants is required. Simultaneously, significant technological developments such as reductions of the energy and material demand for the plant construction and operation can be expected in the future. This study quantifies the potential environmental impacts of a 1 GW proton exchange membrane water electrolysis (PEMWE) plant in a cradle-to-grave bottom-up explorative pLCA considering the anticipated technological developments until 2050. Furthermore, a set of scenarios for the socio-economic transition of the background until 2050 are analyzed and compared.

The functional unit comprises the production of 1 kg green hydrogen from a 1 GW PEMWE plant considering its construction, operation and decommissioning. A state-of-the-art plant is constructed and operated in Europe in 2023 and compared to two technologically developed cases, with respectively reduced energy and material demands in 2030 and 2050. The product system is modelled from the bottom up in Brightway2 and the life cycle inventory is derived from electro-chemical modelling of the plant. The model approach allows a detailed tracking of the environmental impacts through all system layers down to the raw material level and enables full transparency. Potential transition pathways of the background system are depicted with PREMISE. The study focuses on the impact categories global warming potential (GWP) and the abiotic resource depletion of elements (ADPe).

The study shows that the GWP results fan out according to the respective transition pathways and can be drastically reduced over time in all analysed scenarios. Furthermore, it can be deduced, that the de-fossilization of the background system has a considerably larger influence on the impact reduction potential than the technological development of the plant. The ADPe results fan out likewise, however increase by more than 100 % in all scenarios over time. For both impact categories, the plant operation dominates the impacts in all scenarios, however decreasing somewhat in importance for the GWP and increasing for the ADPe.

It can be concluded, that the potential environmental impacts of the large-scale green hydrogen production heavily depend on the implemented climate policies in the future and therefore are, to some extent, subject to political action.

1.01.B.T-08 Prospective Life Cycle Assessment of Hydrogen Production with Next-Generation Low-Iridium PEM Electrolysers

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The latest advancements in proton exchange membrane water electrolysers (PEMWE) for hydrogen production, highlight the need for increased manufacturing capacity and the challenge of relying on critical raw materials like iridium and platinum. However, the effectiveness of electrolysers hinges on the broader decarbonisation of the energy system, underscoring the importance of analysing future electricity and its impact on hydrogen production.

This paper presents a comprehensive prospective life cycle assessment (pLCA) on the fabrication and use of a next-generation PEMWE, which incorporates novel approaches to reduce iridium content without compromising its efficiency and its ecological footprint.

The functional unit is 1 kilogram of hydrogen at 30 bar, with a cradle-to-grave approach. The chosen impact assessment method is ReCiPe 2016 (H). The “premise” tool is utilised to create the prospective background database. For the fabrication of the low-iridium PEMWE an evolving life cycle inventory (LCI) and operational parameters are employed. For the use phase, the electricity scenarios derived from the optimised energy scenario for Germany are applied. For the end of life, an economical allocation was considered.

The PEMWE stack and plant play no significant role, most emissions are attributable to electricity generation. The significant reduction in impacts from electricity is not only due to a reduction in the impacts of electricity but also to an increase in the efficiency of the electrolysis stack. The production of electricity-based hydrogen is not yet viable from a climate perspective compared to conventional grey hydrogen. However, this changes with an increase in the share of renewable energy in electricity generation. The pLCA allows identifying direct trade-offs from the electrolyser fabrication, performance, and use, including the consumed electricity and the whole supply chain and background processes, which gives a more comprehensive understanding of the system.

This study offers a comprehensive examination of the fabrication process and use of a next-generation PEMWE. Our findings underscore the critical importance of updating background data, which serves as a primary driver influencing the environmental impacts of hydrogen production. While infrastructure development for the electrolyser plays a subordinate role in comparison, the efficiency of the system and its consequent electricity consumption emerge as pivotal factors.

1.01.B.T-09 Prospecting for a Biobased Alternative – Climate Assessment of an Industrial Surfactant

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Background

The impacts of producting biomaterials can outweigh the benefits of avoiding fossil ingredients. Avoiding such regrettable substitution entails various prospective LCA challenges. The case in question here is the development of a biobased alternative to a surfactant used in the paper industry. Conventionally, the particular surfactant is an ester of polyethylene glycol (PEG) and forestry byproducts. Our laboratory work has investigated using glycerol products as an alternative to PEG.

Methods

Our LCA has the functional unit of the production of a tonne of surfactant. For the conventional system, primary industrial data for the foreground system were available. For the biobased system, primary laboratory scale data were available for the foreground system. Some commercial database information was available for the background systems.

Heat capacities were unavailable for the forest industry byproducts, so we applied a quantitative structure-activity relationship model. Finding LCI data for the glycerol product was a challenge requiring some imagination. The commercial LCA software contained some LCI data but it cannot be found searching for glycerol – the synonym glycerine is necessary. The ecoinvent database had more, but most of it is not found in the software unless the user searches for "esterification". Searching in the GLAD or openLCA Nexus metadatabases was easier than in the original databases.

Results

Preliminary results indicate a carbon footprint of 1968 versus 687 kg CO2-e/tonne of surfactant for the conventional and biobased cases, respectively. One of the questions that arose during the work was how to consider the embodied carbon in the biobased product versus the fossil product. A cradle-to-gate LCA including biogenic carbon is possible, in which case the biobased product shows a credit and the fossil product none. Instead we chose a consequentialist alternative, counting the emission of carbon dioxide on breakdown of the fossil product after use with an indicator that excludes biogenic carbon. This involves simpler assumptions.

Conclusions

This work showed the value of QSAR application in LCI data acquisition, the benefit of creative use of search terms and LCI metadatabases, and the value of selecting system boundaries and indicators in a way that is consistent with the question under evaluation. It also quantitatively showed a benefit from introducing a biobased chemical.

1.01.B.T-10 Ex-ante Life Cycle Assessment of Bauxite Residue Vitrification Technology

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The increasing importance of developing novel technologies with reduced environmental impacts has driven a need to determine their environmental performance, both for sense-checking their potential and supporting early technology optimisation, which is possible by using the ex-ante life cycle assessment (ex-ante LCA). However, a lack of data and large uncertainties are key challenges to assessing such novel technologies. Here, we study the environmental performance of a novel vitrification technology for bauxite residue recycling into a supplementary cementitious material by quantifying how it changes alongside technology development. We determine the influence of scale (i.e., lab, pilot, and industrial) and upscaling approach at the industrial scale (i.e., proxy technologies, regression analysis, and process modelling) to evaluate the environmental performance of a novel vitrification technology. The findings indicate significant improvements in all impact categories during technology upscaling, with impact reductions of approximately 92-99% from laboratory to industrial scale and 69-86% from pilot to industrial scale. Upscaling resulted in a notable increase in the share of direct emissions contribution during vitrification, due to optimisation of other unit processes (i.e., milling). Despite the scale-up, the vitrification unit (i.e., furnace) remained a major hotspot. Decarbonizing the electricity mix based on future trends reduced climate change impact by 59%, fossil depletion by 78%, human health impacts by 59%, ionizing radiation by 67%, and particulate matter formation by 84%, while metal depletion increased by 9%, indicating burden shifting. The study reveals a small variance (< 2%) among upscaling approaches, highlighting their comparability and interchangeability. Additionally, this study provides a first approximation of environmental impacts related to Bauxite residue vitrification, offering insights into major hotspots, and enabling early-stage optimization before industrial-scale implementation.

1.01.C.T-11 Quality Before Quantity? Considering Material Properties in Prospective Modelling of Recycling

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As recycling technologies emerge for materials that have previously not been recycled, new uncertainties arise. These include which impacts the recycling process cause, the quality of the recycled materials, and quality requirements on the recycled materials to be used in a secondary application. In this study, we explore how to include different quality indicators for the secondary material, as well as their influence on the impacts of emerging recycling systems, in life cycle assessment.

We use recycling of carbon fibre composites as a case study to illustrate the influence of quality indicators and how they are considered when assessing recycling. Carbon fibre composites are light and strong, and often used to decrease the weight of vehicles and consequently their fuel consumption, but the energy-intensive production phase counteracts environmental benefits from a lower fuel consumption. However, it has been shown that recycling of the composite and recovery of the fibres for a secondary application could remedy this, if eventually implemented at large scale.

This study provides insights on how to choose an appropriate quality indicator in prospective life cycle assessment of recycled materials. We first identify relevant quality indicators for recycled carbon fibres by using the literature, and discussions with carbon fibre experts when needed. We then apply these quality indicators in case studies for two emerging recycling technologies: Solvolysis by means of acetic acid and microwave radiation pyrolysis. Additionally, mechanical treatment and conventional pyrolysis are included as they are the most commonly (yet sparsely) used recycling technologies for carbon fibres today. The emerging technologies with lower technology readiness levels were upscaled to represent an industrial scale.

Preliminarily, six relevant quality indicators for recycled carbon fibres were identified. Initial results show that there is a trade-off between generating high quality materials and having low environmental impact. The environmental impact in a comparative study is, however, strongly influenced by the choice of quality indicator. We provide and evaluate different suggestions on how these can be considered in the prospective assessment for more relevant comparisons, for example by altering the functional unit, or by letting the impacts of the recycling process depend on what materials can be substituted downstream.

1.01.C.T-12 Discovering the Sustainability Conditions for Future Agrivoltaic Deployment via Parameterized LCA

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Agriculture faces increasing food demand in a context of climate challenges like extreme weather and water scarcity. Concurrently, renewable energy, particularly solar power, requires more land. To address land competition and stabilize conditions for crops, agrivoltaic systems (AVS) is proposed as an emerging technology which places photovoltaic panels (PV panels) above agricultural areas. With such a broad definition, AVS performances are very diverse and depend on the application context (crop type, climate, land, and electricity market etc.) and the technology (PV efficiency, crop yields etc.) impacting electricity and agricultural production differently. However, few LCA studies exist covering only a fraction of AVS's diversity and thus, hindering a comprehensive understanding of their environmental impacts crucial for policy decisions on future deployment. Our work aims at discovering and analyzing the AVS configurations, both technological and contextual, that must be avoided or favored to ensure the environmental competitiveness of AVS versus its conventional counterparts (conventional PV plants and crops).

To do so, we developed a highly parameterized consequential LCA model that can account for various factors including technological advancements, agricultural practices, and market contexts. The model can simulate two consequential hypotheses for AVS development, namely driven by electricity or crop demand. Parameters adapted from an existing photovoltaic (PV) model define manufacturing advancements in PV technology and crop production. Other parameters reflect technological and agronomical changes, differences in technologies and efficiencies between AVS and conventional activities (interactions), and indirect land use changes (iLUC).

After running thousands of Monte Carlo simulations with varying input parameter values, we used the PRIM algorithm for scenario discovery to identify AVS configurations to avoid or favor based on specific impact conditions. We thus explored scenarios where AVS underperform or outperform conventional PV and crop productions, highlighting sensitive parameters and general conditions for AVS competitiveness.

Thanks to stochastic approaches coupled with scenario discovery, our findings provide insights for guiding future AVS deployment and ensuring their environmental competitiveness. We emphasize the importance of proactive planning to promote sustainable technology adoption and address global challenges.

1.01.C.T-13 How Do Future Scenarios Impact Environmental Outcomes? Prospective Life Cycle Assessment Of Passenger Cars

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Life cycle assessments (LCA) typically use present-day data for all life-cycle stages. This approach needs improvement for cases like passenger cars to obtain representative outcomes. For instance, manufacturing impacts occur in year 0, use from years 0-14, and end-of-life in year 15. Applying year 0 impact factors to future use and end-of-life stages results in a temporal mismatch, given expected changes in factors like the electricity and fuel mixes.

We conduct a time-adjusted prospective LCA (pLCA) on passenger cars to investigate future scenario influence on environmental outcomes. First, we incorporated four 1.5-3.0°C aligned decarbonisation scenarios from the TIMES Integrated Assessment Model at University College London (TIAM-UCL) into PREMISE for major sectors like electricity and fuels. Second, we developed a pLCA model adjusting for vehicle stages based on manufacturing, use, end-of-life years, and future scenarios based on 'carculator' and battery recycling inventories. Third, Monte Carlo (MC), Global Sensitivity Analysis (GSA), and EF 3.1 methods were used in the pLCA model to assess the influence of future scenarios on environmental outcomes compared to mileage, vehicle size, and region.

10,000 MC runs compared the global warming potential (GWP) of battery electric vehicles (BEV) and mild hybrid combustion vehicles (HEV). A typical LCA would find that BEVs have, on average, 23% lower GWP and win in 89% of cases. However, a pLCA with time-adjusted future scenarios shows that BEVs, on average, have 41% lower GWP and win in 99% of cases. This is primarily due to greater expected regional decarbonisation in future electricity mixes compared to limited decarbonisation in fuel mixes. GSA identified that regional electricity mix carbon intensities significantly influenced BEVs' winning margin. However, future scenarios had the most significant influence on the margin within regions with higher carbon electricity mixes due to the greater regional decarbonisation potential.

Our pLCA demonstrates that a time-adjusted approach with future scenarios improves impact representation and environmental outcomes. Time-adjusted pLCA showed that BEVs likely have greater GWP benefits than typical LCA suggests and considering 1.5-3.0°C future scenarios is crucial in study outcomes. We recommend using time-adjusted pLCA in future-oriented sustainability decision-making, especially for long-lived products with life cycle stages distributed over time.

1.01.C.T-14 Prospective Life Cycle Assessment of The Emerging Technology in Circular Economy Context

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Emerging technologies can promote circular economy, while the enveiomental impact assessments of emgering technologies are necessary to drive the development of emgering technologies with better environmental performance. This study applied a prospective (ex-ante) consequential LCA for an emgering technology (TRL 5-6) proposed to process digestate and recover resouces, e.g., biofertiliser and water. The emerging technology consists of several digestate treatment technologies, i.e. solid-liquid separation, antibiotic removal, and nutrient recovery processes. Recovered biofertiliser can replace mineral fertiliser, while recovered water can satisfy the needs of the AD plant and be exported to replace tap water for irrigation. The goal of this study was defined to explore environmental impacts of introducing the emgering technology into a UK's AD plant in 2030, when it is avaiable at commerical scale. Four impact categories were focused on, including climate change, freshwater eutrophication, terrestrial acidification, and water consumption. The results show that environmental impacts caused by the operations of the upcalsed technology for the AD plant are minimal for all four impact categories studied. Meanwhile, the introduction of the technology into the AD plant can save, for per tonne digestate processed, 31.4 kg CO2eq of cliamte change impacts, 8.3 g Peq of freshwater eutrophication imapcts, 2.1 kg SO2eq of terrestrial acidification impacts, and 0.6 m3 of water consumption imapcts. This indicates that introducing the digestate treatment technology into the AD plants in 2030, when it is upscaled to commerical level, would be benefical for the AD industry in the UK from environmental perspective.

1.01.C.T-15 Sustainable Aviation Fuel from Kraft Lignin – Life Cycle Assessment in Early Stage Research and Development

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Sustainable aviation fuels (SAF) are of key importance to reduce greenhouse gas emissions, especially for long distance transport, where no other viable alternative is currently available. The EU-project ABC-Salt investigated a novel production route for jet fuel from lignocellulosic waste streams, in particular Kraft pulp mill lignin. However, potential production cost and benefits in terms of environmental impacts are hard to quantify for a process at lab-scale development stage. Therefore, chemical engineering know-how was applied to scale up the process to a commercial production scale and use the resulting process simulation as a basis for a life cycle assessment (LCA).

DLR's in-house tool TEPET+ semi-automates the process simulation based LCA of chemical processes and technologies by enabling the user to link Aspen Plus® process simulation information to background data from LCA databases like ecoinvent. The thereby generated life cycle inventories are then automatically transferred to Brightway2 for the life cycle impact assessment. By linking LCA to process simulation data the investigated process can firstly be assessed at commercial scale and secondly process parameter studies can be easily performed.

The environmental impact breakdown reveals Kraft pulp mill lignin as the main contributor to almost all categories of the Environmental Footprint method. When different allocation approaches are compared for the multi-output pulp mill process, a significant range (11 and 26 gCO2 eq./MJ) of global warming potentials (GWP) is found for the SAF. Overall, many impacts are increased compared to fossil jet fuel, suggesting that the applicability of other lignin or biomass sources should be emphasised in future research as the conversion efficiency is already quite high. A parameter study on the recovery rate of unreacted hydrogen shows that the GWP can be reduced for higher recovery rates because the hydrogen supply decreases although the membrane area for the hydrogen separation increases exponentially.

Utilising chemical engineering knowledge to create process simulations provides a great basis for the LCA of processes in its up-scaled version. You not only obtain a more realistic view of the potential environmental impacts of the process but parameter studies can also provide indicators for process improvement. The ABC-Salt process could become a promising SAF production route if the impacts related to lignin can be reduced.

1.01 P - Advances in Prospective Life Cycle Assessment

1.01.P-Mo001 Prospective LCA Applied to Emerging Production Process of a Novel Protein from Woody by-Products: a Tentative Analysis

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Background and Purpose

Meeting the growing demand for farmed fish necessitates differentiating feed ingredient production. An emerging process combining pyrolysis, syngas conditioning, and fermentation can transform wood resi-dues from sawmills into a novel protein feed ingredient known as single cell protein (SCP) to be used in aquaculture industry, as well as biochar for animal feed. The aim of this study is to assess the key environmental impacts of producing SCP. Assessing technology in early stage could contribute to achieving lower greenhouse gas emissions, reduced land and water use and overfishing, compared with traditional feed ingredients such as soybean and fish meal.

Methods

A prospective life cycle assessment (LCA) methodology is applied to the above-mentioned process at an early stage. The study assesses key environmental impacts such as climate change, land use, water scarci-ty, resource scarcity, and biodiversity. Currently, data is collected from lab-scale studies. Primary data encompass details regarding necessary raw materials, energy use, consumables, emissions, waste streams, and other factors across the various tech-nological process stages. Data linked to anticipated efficiency enhancements during the transition from lab -scale (TRL 4) to prototype pilot demonstration (TRL 6) are also under collection.

Results
Preliminary results to produce novel SCP at lab-scale and extrapolated full-scale will be presented. Several parameters such as water and energy requirements, amount of chemicals used, equipment capacity, gener-ated process water, emissions, and waste fractions, etc. may change when the full-scale production pro-cess is implemented, hence affecting the environmental performance of novel process. Therefore, to as-sess different operative conditions when moving from a lab to a full-scale production process, an upscaling analysis needs to be performed. This will be done by using power laws and scenario analysis to simulate the future full-scale operation conditions.

Conclusions
The results of this study will provide a step forward in the development of LCA results for alternative protein sources, as such results are scarce. The novelty of the study is to complement research gaps in LCA literature, addressing the environmental impacts (not only climate change or fossil resources, which is often assessed in screening studies) of aris-ing technologies in waste handling and feed production. The results of the study can support industry in the phase of implementation of emerging technologies.

1.01.P-Mo002 Prospective Life Cycle Assessment of Platform Chemicals Produced via a Biotechnological Pathway using Carbon Capture and Utilization as Feedstock
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In recent times, there has been a great deal of focus within research as well as within industry on the shift away from crude-oil-based feedstocks towards renewable feedstocks, especially in the chemical industry. The current work focuses on analyzing the environmental impacts of novel technologies which enable circularity in the chemical and polymer industry. The system under study is a novel biotechnological cascade designed to valorize the captured carbon dioxide emissions from the chemical industry to produce platform chemicals and monomers, such as dihydroxyacetone, which can then be used to produced novel polymers.

The main challenge in performing such an LCA lies in analyzing how the technology can be upscaled and how it would interact with the market in the future. Moreover, the technology under review is currently between technology readiness level four and six, so in addition to the technological upscaling, it is also necessary to account for the time required until the technology is ready to be deployed commercially. A further challenge lies in the open-loop circular nature of the technology under review since it uses valorized carbon dioxide emissions as the primary feedstock- Yet another challenge lies in the fact that the primary feedstock is carbon dioxide, which necessitates accounting for the temporal effects of utilizing carbon dioxide on the climate change impact category.

To address the initial challenge, a series of upscaling scenarios for feedstock valorization, biotechnological cascading, and polymerization are created based on the most prevalent technologies currently employed in the industry. These scenarios have then been combined with prospective background scenarios to understand the impacts of different energy mixes on the supply chain. Finally, a comparison has also been drawn with conventionally produced dihydroxyacetone.

To address the circularity issue between two life cycles, different cut-off methods, including the circular footprint formula, are implemented to understand how this choice impacts the overall results of the technology under review. In addition to the standard cut-off methodologies, a purely economic-based approach is also implemented to understand whether this provides useful results. At this stage, the results are still preliminary to form concrete conclusions. However, this project serves as a use case for applying LCA to prospective circular technologies.

1.01.P-Mo003 Prospective Life Cycle Assessment of Bio-Based Polymer Intermediate Products – Identifying Potential Benefits and Challenges
Helena Monteiro, ISQ; Diogo Teixeira, Instituto de Soldadura e Qualidade; Daniel Silva, Instituto de Soldadura e Qualidade.

Background and Purpose: With increasing awareness of the environmental impacts of human activities, the plastic industry, still heavily reliant on fossil-based resources, has become a significant concern. To enhance European industrial sustainability, a common approach involves using renewable feedstocks for polymer production and promoting circular value chains from second- and third-generation feedstocks. The BIOMAC project operates within this context, developing valuable bio-based intermediate products with potential applications in various polymeric test cases. This study aims to identify potential environmental hotspots and provide early guidance for sustainable process scale-up.

Methods: This research employs the life cycle assessment (LCA) methodology, following the ISO 14040 and ISO 14044 standards, and explores prospective LCA to estimate the potential environmental impacts throughout the life cycle of different products being developed within the BIOMAC bio-plastic value chain. By analyzing the inputs and outputs of process steps at early stage of development, and estimating scale up scenarios, the study aims to pinpoint critical areas where environmental impacts are likely to be most significant, that should be addressed prior the scale-up.

Results: The LCA revealed several potential environmental hotspots in the production and development stages of the bio-based products. These hotspots, mostly associated to energy consumption, wastewater generation, and specific inputs, highlight areas where modifications can reduce environmental impacts. The study also compares the findings with existing literature benchmarks, contextualizing the results and offering insights into how the BIOMAC products perform relative to conventional fossil-based alternatives. The challenge of defining prospective scenarios of scaling up are also highlighted.

Conclusions: The findings of this study are supporting the development of bio-based products, offering potential environmental benefits, while addressing challenges related to product functionality, process efficiency, and future end-of-life scenarios. By identifying environmental trade-offs and areas of concern, at early development stages, the study supports informed decision-making for sustainable product design and process scale-up. The insights gained contribute to current knowledge and provide a foundation for developing more sustainable bio-based intermediate materials expected.

1.01.P-Mo004 Controlled Environment Agriculture in Prospective Energy Scenarios
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Controlled Environment Agriculture (CEA) holds many advantages over conventional farming methods, such as allowing intensive farming on non-arable land, reducing pesticide and water use, and enabling crop production to be independent of local climates. While they are promising technologies in a future of increasing food demand due to population growth and affected yield due to climate change, immense energy used in artificial lighting using current energy grids inevitably attributes large carbon emissions to these emerging ventures. Hence, it is vital to develop CEA ventures while considering prospective energy scenarios where these technologies will be critical, as arable land is finite and heavily competed for energy, food, cultural, and climate mitigation uses.

In this study, a prospective Life Cycle Assessment (LCA) database previously developed was applied to a prospective CEA facility producing wheat. Transport emissions of various wheat importers globally were calculated, and potential locations where CEA can serve as import substitutions are highlighted.

Preliminary results highlight the sensitivity of CEA carbon emissions to the renewable energy composition in the prospective energy grid. Reasonable energy usage for import substitution by CEA venture can also be calculated. Considering state-of-the-art CEA of other lower calorific value crops, we find that the energy usage performance of these ventures could already be viable import substitution in selected prospective energy scenarios. These results serve as an energy usage target which CEA ventures can optimise towards. These results could also be used as prospective data points towards which prospective alternative protein production can be studied.

1.01.P-Mo005 Prospective and Life Cycle Assessment in Sustainable Building Practices: The Role of Sustainable Materials

Dante Maria Gandola, University for Foreigners of Perugia; Francesco Asdrubali, University for Foreigners of Perugia.

The urgent need for the construction sector to reduce greenhouse gas emissions presents a critical global challenge, as buildings play a significant role in energy consumption and environmental impact. The Italian project, CHOISIS, is dedicated to addressing this challenge by characterizing the environmental and thermophysical properties of innovative insulating materials. This initiative aligns with the European Union's ambitious goal of achieving zero-emission buildings by 2050.

The research conducted under the CHOISIS project incorporates Life Cycle Assessment (LCA) methodologies to forecast the long-term environmental impacts of new building materials, thereby supporting sustainable development objectives. The study evaluates the Global Warming Potential (GWP) of key materials such as concrete, expanded polystyrene, and bricks, utilizing standardized international protocols. Additionally, it assesses the environmental impact of innovative materials like aerogels, nanorenders, and those derived from agricultural waste, emphasizing their potential to reduce thermal transmittance and carbon footprints.

The findings of this research underscore the significance of Environmental Product Declarations (EPDs) in enhancing environmental performance and promoting circular economy principles within the construction industry. By leveraging EPDs, construction projects can attain sustainability certifications and adhere to green building standards, emphasizing the importance of validated environmental information.

The results of the CHOSIS project demonstrate the transformative potential of innovative materials in propelling the construction industry towards a sustainable future. These insights offer practical guidance for widespread implementation across the industry to effectively mitigate environmental impacts.

1.01.P-Mo006 Life Cycle Assessment for Eco-design of Bioactive Chemicals from Biorefinery Side-streams

Ellen Soldal, NORSUS; Ingunn Saur Modah, Norwegian Institute for Sustainability Research (NORSUS); Andreas Brekke, Norwegian Institute for Sustainability Research (NORSUS).

The Borregaard biorefinery in Norway produces a range of bio-chemicals based on Norway Spruce. In the project BACS (short for BioActive Compounds from Spruce), the goal was to develop sustainable value-added products that are bioactive or that will stimulate and improve the bioactivity of other compounds in formulations. Sustainability was to be used as a guideline for decision making during process development. The long-term goal was to be able to upscale such processes from lab scale to commercial production.

The study has used attributional environmental life cycle assessment (LCA) methodology in cradle to gate analyses. The indicators used were for climate change, acidification, eutrophication, water scarcity and use of fossil energy resources.

Bark and knots were explored as feedstocks, going into four compounds:

- Terpene from bark
- Bark extract (containing stilbenes)
- Bark residue (containing polysaccharides and tannins)
- Knot extract (containing resins and conidendrin)

LCA was used to give input to the innovation process by identifying environmental hotspots. Draft models were analysed and preliminary results were presented and discussed with representatives from the biorefinery in several rounds. Scrutinizing the burdens of each product and discussing alternative options, focusing on the hotspots and following the burdens upstream, led to ideas on how to optimize the systems. This work process also revealed human errors; hence it served as a quality check of the input data and modelling.

The draft results were documented as the LCA models were refined in this iterative innovation process. Hence, the development of the results show both how potential technical improvements and quality checks of the input data and the LCA model itself, have affected the results. The main hotspot issues found during the project were related to separation of terpene and ethanol recirculation; the first being important for the terpene result while the second affects bark extract and knot extract to a large extent. The main corrections of human errors in the LCA model were related to the pelletizing process and production of steam. The key lessons learned are that important environmental improvements, as well as modelling errors, can be found using LCA in such an iterative collaborative innovation process. It is, however, crucial to recognize that misunderstandings can easily arise, and that time must be spent on discussing details as well as the bigger picture.

1.01.P-Mo007 Are Climate Neutrality Potential and Circularity Potential New Impact Categories in LCA? - A Case Study on Trucks

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Laboratory; Nikolas Hill, Ricardo; Simone Ehrenberger, German Aerospace Center (DLR); Gabriela Benveniste Pérez, IREC; Víctor José Ferreira Pérez, IREC; Linda Ager-Wick Ellingsen, Norwegian Centre for Transport Research; Marco Raugei, Ricardo Energy & Environment; Christian Bauer, Paul Scherrer Institute; Ocktaeck Lim, University of Ulsan; Farid Bensebaa National Research Council Canada; XiaoYu Wu, National Research Council Canada; Tugce Yuksel, Sabancı University.

Background and Purpose
Climate neutrality and circularity are two main challenges for a sustainable development. Circularity and climate neutrality can only be addressed by the methodology of dynamic Life Cycle Assessment (LCA), where GHG emissions, resource demand and material recovery are calculated and assessed over the total life time from construction, operation until the end of life management of a product or service.

Climate Neutrality and Circularity can be assessed in LCA based on the GHG emissions and the mass flows over the lifetime. For this a LCA based definition of Climate Neutrality and Circularity is necessary, which is given in the following. To keep the wording appropriate to LCA nomenclature, it is named the LCA based Assessment of "Climate Neutrality Potential (CNP)" and "Circularity Potential (CPO)". These definitions were developed in the IEA HEV Task 46 and applied for the first time in the LCA case study on trucks.

Methods
The new indicators for the assessment in the dynamic LCA are the

Circularity Potential (CPO): Based on data of Inventory Analysis with the mass flows in and out of the system over the lifetime using the Material Circularity Index (MCI): 100% = circular (whereas: 0% = linear) whereas the Linear Flow Index of materials (LFImaterial) and the Utility Factor of product (UFproduct) are used: MCI = LFImaterials * UFproduct

Climate Neutrality Potential (CNP): Based on GHG emissions from Impact assessment using the total radiative forcing at top-of atmosphere based on GHG emissions over lifetime: $W/m^2 = 0$; "Towards Climate Neutrality" means zero GHG emissions in operation phase and no change in radiative forcing in the year 2100: delta $W2100/m^2$

Results

A methodological framework to assess climate neutrality and circularity is developed and applied in a case study to compare trucks with different propulsion & fuel combinations, e.g. battery and catenary electric trucks, diesel, e-diesel and H2 trucks. All systems use additional renewable electricity and the e-diesel uses CO2 from air.

The Circularity Potential of a diesel truck is 3% - 6%, whereas for an electricity battery truck it is 71% - 77%, for a hydrogen truck 67% - 69% and e-fuel truck 59% - 61%.

The Climate Neutrality Potential in year 2100 of a diesel truck is 7.8*10-11 to 8.3*10-10 mW/m^2 for a battery truck 1.2*10-11 to 2.2*10-10 mW/m^2, for a hydrogen truck 1.7*10-11 to 2.5*10-10 mW/m^2 and e-fuel truck 2.7*10-11 to 2.9*10-10 mW/m^2.

Conclusions
The Circularity Potential as well as the Climate Neutrality Potential are assessd in a dynamic LCA and these potentials add additional environmental relevant categories not yet covered by the existing LCA impact categories. These possibel new impact categories offers the opportunity to identify products and services that have the principal potential to become circular and climate neutral. This is shown in a case study on trucks.

1.01.P-Mo008 Prospective Life Cycle Assessment of Solvolysis Recycled Carbon Fibres and their Potential Application in the Transport and Building Sector

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Due to the high energy input and consumption of non-renewable resources for the production of today's virgin carbon fibres (vCF) based on Polyacrylonitrile (PAN), their multiple use in a potential circular economy seems desirable from economic and ecological point of view. The EDISON-rCF* project demonstrates the potentials of a recycling process chain for carbon fibre reinforced polymers (CFRP). One- and two-dimensional semi-finished products for subsequential use in the transport and construction sectors were developed and tested based on recycled carbon fibres (rCF) obtained from an improved Solvolysis process.
In a Life Cycle Assessment (LCA) for CFRP based lightweight systems the modelling and interpretation of a future cascading product system is a challenge because of Life Cycle Inventory (LCI) data quality and allocation methods. The availability of reliable data for the virgin carbon fibre production is limited and literature data shows considerable scattering of energy consumption and incompleteness regarding the covered phases of the production. Particularly in the recycling of high-performance materials such as carbon fibres, attention must be paid to potential performance losses (downcycling) and corresponding influence on their applicability. An important factor for the establishment of recycling routes is the creation of incentives for the recycling including a useful application of such materials. The allocation of potential environmental impacts based on different EoL Formulas plays a crucial role here.
The presentation sheds a light on the preliminary results for the use of rCF in two potential use-cases, a bicycle transport box and rebars for carbon concrete. For this, the whole process chain from a cradle-to-gate perspective was modelled using foreground and background data with different level of completeness. Therefore, the uncertainty of this prospective LCA is high and shows the potential shortcomings of incomplete data based on missing information and low technology readiness level.
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1.01.P-Mo010 Prospective Life Cycle Assessment of Wind Power Production: What Role Could Wood Play in the Future?

Lea Braud, KTH Royal Institute of Technology; Fabian Cheng, KTH Royal Institute of Technology; Elisabeth Ekener, KTH Royal Institute of Technology.

Wind power is essential to achieving the European Union's climate neutrality by 2050. Due to the increasing demand for renewable energy, the wind farm's total installed capacity will be tripled by 2030. With the rapid development of technologies to increase the efficiency of wind turbines, there is a need to ensure that the new generation of wind turbines will reduce environmental impacts of energy production.

This study evaluates the potential of wood versus low carbon steel and concrete to replace conventional materials in the construction of wind turbines and mitigate the environmental impacts of wind power production in Sweden by 2050.

A prospective life cycle assessment (LCA) was performed using Brightway to assess the environmental impacts associated with the production of 1 kWh of electricity from a generic onshore wind power plant located in Sweden. The Python libraries lca_algebraic and premise were used to parameterise the foreground system model and generate prospective background databases, respectively. Several scenarios were compared in which novel technologies were deployed at low or high level, focusing on the use of low-carbon and bio-based materials.

The results show that low-carbon and bio-based alternatives could play a key role in mitigating the environmental impacts of wind power production in the future. Carbon capture during biomass production and its storage over the life cycle of the wind turbines was accounted for following the recommendations from the EU funded ALIGNED project. However, more research is needed to address the methodological challenges associated with the development of future scenarios for the bioeconomy and their integration within prospective LCA.

1.01.P-Mo011 Bottom-Up Scenarios for Critical Raw Materials Supply Linked to Prospective Life Cycle Assessment

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Background and purpose: The demand for critical raw materials (CRMs) such as lithium, cobalt or graphite is anticipated to surge in the future, driven by the large-scale deployment of clean energy technologies like electric vehicles. These prospects raise significant concerns about the future environmental impacts resulting from the expansion of mining and refining capacities to meet the growing demand. Assessing the future impacts of CRM supply is hindered by the high heterogeneity across production sites, exacerbated by the current lack of supply scenarios for use in prospective life cycle assessments (LCAs).

Methods: Here we introduce a bottom-up approach for developing CRM supply scenarios on a project-by-project basis. Our approach leverages extensive information on current and future production sites compiled in the S&P IQ Capital Pro database. The available information includes data on current and forecasted production volumes derived from companies announcements, which we use to develop commodity-specific supply scenarios up to 2040. We further estimate missing forecasted production volumes from other project data, such as historical production, projected closure year, production capacity, and project lifetime. Moreover, we establish three supply scenarios to capture the uncertainty surrounding future projects. While the Business-as-Usual (BAU) scenario includes only projects that are already operating or under construction, representing low risk, the Ambitious and Very Ambitious scenarios further consider the successful development of projects that are still in early stages of development.

Results & conclusions: The developed supply scenarios can be exported in a format that is directly compatible with the premise framework, and usable alongside global scenarios from Integrated Assessment Models (IAMs). In this process, a match between the bottom-up CRM supply scenarios and the IAM's global scenarios is assumed. Specifically, the BAU scenario is assumed to align with a baseline climate policy scenario, indicating relatively lower expansion of CRM production for clean energy technologies. Conversely, the Ambitious and Very Ambitious scenarios are assumed to align with the 2 ºC and 1.5 ºC scenarios, respectively, implying a rapid expansion of clean energy technologies coupled with a swift development of CRM projects. Eventually, the supply scenarios can be linked to site-specific life cycle inventories (LCIs) for each project. On-going work will showcase the potential of our bottom-up approach through the example of lithium carbonate production from brines.

1.01.P-Mo012 How to Engage Stakeholders in Scenario Development for Prospective LCA?

Brais Vázquez Vázquez, Universidade de Santiago de Compostela; Ángeles Val del Río, Universidade de Santiago de Compostela; Almudena Hospido, Universidade de Santiago de Compostela.

1. Introduction

Prospective Life Cycle Assessment (pLCA) employs future scenarios to explore the environmental impacts of emerging technologies after their full scale implementation. PRETENACC is a novel technology that aims to valorise industrial lipidic waste streams, by producing polyhydroxyalkanoates (PHA), in a single-unit. Following the stepwise approach to scenario-based inventory modelling for pLCA (SIMPL) an external network of stakeholders is needed to identify the parameters which will influence the upscaling of the process and to build and validate future scenarios, and the process and dynamics to engage stakeholders is the focus of this contribution.

2. Methods

Stakeholders identification is the first step requires an exhaustive classification and selection of stakeholders who will assist the pLCA practitioner, and a PESTEL (i.e. Political, Economic, Social, Technological, Environmental and Legal factors) analysis is the recommended procedure to do so.

Selected stakeholders are then convened for a face-to-face meeting, establishing prior individual contact informing about the task to be developed, why it is he/she necessary for and the list of all expected attendants.

After a short round of presentations, the meeting was structured in two main blocks: a theoretical one where the emerging technology and the pLCA methodology are presented; and a practical one where the process flow diagram is analysed to identify the key parameters i.e. PESTEL variables that significantly influence future scenarios and results.

Then, sub-scenarios are developed and consistency check performed to exclude the most improbable combinations. A manageable number of final scenarios should be agreed and the correspondent narrative developed.

3. Results and Discussion

The PESTEL analysis identified a total of 58 stakeholders, so a filtering process was applied to reduce it to a manageable number for an effective meeting (10-15 people). Criteria used were the representativeness of private and public sector, gender, contactability and experience. The stakeholder meeting generated a total of 27 parameters (5 environmental, 3 economic, 2 legal, 7 political, 5 social, and 5 technological); that, after the correspondent consistency check, produced a total of XX scenarios and their related narratives.

1.01.P-Mo013 Analysis of the Philosophical Foundation of Foresight and its Implications for Prospective Life Cycle Assessment

Anne van den Oever, Vrije Universiteit Brussel (VUB); Daniele Costa, VITO/EnergyVille; Rickard Arvidsson, Chalmers University of Technology; Maarten Messagie, Vrije Universiteit.

In recent years, the subfield of prospective life cycle assessment (LCA) has emerged and continues to develop. Various reviews have been published, an academic network has been established, and the term 'prospective LCA' appears increasingly in scientific publications. As a result, it is expected that prospective LCA will become a critical tool to support decision-making processes. Yet, the discipline's philosophical foundations have not yet been clearly established, neither has its boundaries to other future-related academic disciplines, potentially leading to unclear scope definitions. While acknowledging that overly rigid frameworks should be avoided during the initial stages of a new discipline, this work aims to contribute to the clarification of fundamental assumptions within and behind prospective LCA. To this end, fundamental texts on theories of foresight and future studies are analysed and compared to state-of-the-art scientific articles on prospective LCA and scenario analysis. A preliminary examination reveals Gaston Berger's distinction between studying the near future, which demands immediate action with minimal room for error, and the far future, where a greater tolerance for risk exists as adjustments to undesired outcomes remain feasible. Forecasting, relevant to the near future and foresight, applicable to the far future, require distinct methods that can be used in tandem. The study explores how the distinction between forecasting and foresight can aid prospective LCA in delineating decision contexts and sheds light on the ongoing debates about uncertainty in the field. The subsequent phase of this research aims to bridge the gap between foresight and forecasting in practical application, namely, how to contextualize the outcomes of prospective LCA for the distant future within present-day decision-making. Furthermore, the role of less predictive and more explorative approaches to investigating the (farther) future are analysed, such as backcasting and cornerstone scenarios. The tensions between the assurance of forecasts and the humbleness of explorative approaches will be further analysed.

1.01.P-Mo014 Evaluating Emissions from Polymer-based Solar Photovoltaic Modules in its Pilot and Early Industrial Phase

Prapti Maharjan, Eindhoven University of Technology; Mara Hauck, Eindhoven University of Technology; Arjan Kirkels, Eindhoven University of Technology; Heleen de Coninck, Eindhoven University of Technology.

As global warming intensifies, reducing carbon dioxide emissions becomes urgent. The power sector, particularly coal plants, is a major contributor, accounting for nearly 44% of global CO2 emissions. Decarbonising this sector requires more renewable energy sources, with solar photovoltaics (PV) playing a key role, currently generating 4.5% of global electricity, primarily using crystalline silicon technology. While PV systems are emission-free during use phase, manufacturing emissions are non-negligible and vary by module design (for example: glass-backsheet, glass- glass or polymer-based) and location. Conventional PV modules have received considerable attention, but newer module designs are rarely assessed. Additionally, outdated life cycle assessment (LCA) inventories may overestimate emissions for current crystalline PV modules. Integrating new designs presents challenges, especially when industry data for emerging designs is scarce. Prospective life cycle assessments (pLCAs) offer a way to theoretically calculate emissions using standardised technology designs or expert judgements. However, comparing empirical pilot phase data with industrial data is seldom done. In this study, we evaluate a new polymer-based module layout at early industrial scale and compare it with pilot phase using primary industry data for the foreground system, updated inventory for cell manufacturing and background system using Premise. Our findings highlight the importance of considering new designs and updated inventories for improved life-cycle emission assessments, and offer insights into challenges/uncertainties inherent in early assessments, where industrial data may be lacking.

1.02 - Collecting Internal and Collaborative Data for LCA – Securing Availability and Quality

1.02.T-01 Evaluation of Input Data Quality in Standardized LCA for System Improvements in Continuous Manufacturing Systems

Christina Lee, Chalmers University of Technology; Varun Gowda, Chalmers University of Technology; Gauti Asbjörnsson, Chalmers University of Technology.

Background & Purpose:The rise in demands for environmental information concerning products has now seen the use of LCA within the EPD framework rise among product producers, particularly in the construction sector. Although some construction products are manufactured in repetitive or batch processes due to their specifications, others are produced in continuous processes due to their relationship to a customizable criterion, for example, size or mass.

Aggregates are manufactured using continuous processes, however many of the system inputs occur at discrete intervals which can be challenging for allocation. Further for the data collection, even inputs that are used continuously in the process can be collected at discrete intervals (e.g. electricity bills once a month). Therefore, not only are there temporal variations in the inputs to the system but also temporal variations in the data collection which all lead to assumptions being made while modelling the LCI for a product and can affect the data quality. This contribution explores these variations and their potential impact on data quality for identifying system improvements at the manufacturing level.

Methods:The evaluation is based on observations from three research projects to identify the need for preparing and processing input and output data.

Results: The results show multiple sources for input and output data coming at various time intervals throughout a one year period. The granularity varies for key input and output data.

Conclusions: The results indicate automating data collection is needed to reduce the data collection burden on operators if LCA results are to be used for system improvements at the manufacturing level. However, there are questions around what level of granularity and processing of the data is needed to be useful in identifying improvements at a finer scale than one year. Further, it raises challenges with quality questions that need to be addressed so that the data can be trustworthy for operators considering the various sources for the data that are observed.

1.02.T-02 Leveraging on Digital Data Platform for Data Collection to Underpin Meaningful LCA

Emanuel Lourenço, INEGI - Instituto de Ciência e Inovação em Engenharia Mecânica e Engenharia Industrial; Marco Rodrigues, INEGI - Instituto de Ciência e Inovação em Engenharia Mecânica e Engenharia Industrial; Maria Soares, INEGI - Instituto de Ciência e Inovação em Engenharia Mecânica e Engenharia Industrial; Sara Pinto, INEGI - Instituto de Ciência e Inovação em Engenharia Mecânica e Engenharia Industrial.

Life Cycle Assessment (LCA) is crucial for evaluating environmental impacts across a product's lifecycle. LCA provides a comprehensive view of a product's entire lifecycle, encompassing numerous processes, resource usage, and emissions across various locations and timelines. Despite its importance, meaningful LCA results require a substantial amount of high-quality data, particularly during the Life Cycle Inventory (LCI) phase, which is often complex, time-consuming, and resource-intensive.

SUNDIAL - Digital Data Platform (DDP) addresses these challenges by streamlining collaborative LCA data collection. DDP supports the LCI phase by managing confidential data, developing visual flowcharts/models, enabling multi-stakeholder access, ensuring ISO compliance, and facilitating data validation. The platform simplifies data management with a sector- and product-agnostic approach, enabling easy input and storage of data for any case study.

Leveraging DDP for LCI purposes offers several benefits, including streamlining data collection, enhancing collaboration, and supporting early-stage product development. The platform's automation capabilities, coupled with recent technological advancements in AI and Machine Learning, will enable efficient data collection and analysis, reducing reliance on human interpretation.

In conclusion, SUNDIAL - DDP offers a promising approach to enhancing the effectiveness and transparency of environmental assessments, particularly in LiBs development. By automating data collection and integrating emerging technologies, DDP accelerates progress towards sustainable decision-making across product development landscapes.

1.02.T-03 Towards a Better Approximation of Feed in Environmental Footprint Tools

Veerle Van linden, Flanders Research Institute for Agriculture, Fisheries and Food (ILVO); Anne-Sophie Sacré, Flanders Research Institute for Agriculture, Fisheries and Food (ILVO); Reindert Heuts, Flanders Research Institute for Agriculture, Fisheries and Food (ILVO); Freya Michiels, Flanders Research Institute for Agriculture, Fisheries and Food (ILVO.

1. Background and Purpose

Livestock farming has major impacts on many environmental themes. The livestock sector is expected to lower it's environmental footprint, as requested by several parties (policy makers, consumers, customers). The impact of the feed production is dominant, yet very uncertain, mainly because feed producing companies do not wish to share their recipes. This work is presenting a novel approach to build the Life Cycle Inventory of the compound feed to be used in the Klimrek climate scan, Flanders' environmental footprint tool.

2. Materials and Methods

Two approaches are developed. A first approach is drafting a validation protocol and data sharing protocol for existing footprint systems for core and compound feeds (with exact footprint values) for compatibility with the Klimrek climate scan and according to the international standard of the PEFCR feed. A second approach is establishing a protocol for correctly approaching the footprint of core and compound feeds based on company-specific composition (when exact footprint values are not known) with attention to incentivisation of exact footprint values and a corresponding data sharing protocol.

3. Results and Discussion

The existing footprint systems appeared to differ in various ways. Although they claimed to be compliant with the PEFCR, some of them had serious shortcomings. Causes of deviations were identified and a selection of high impact feed components and feed mixtures were identified for validation purposes. A protocol was developed specifying steps to take and timing.

The identification of the minimally required information on the compound feed that will enable a more accurate assessment of its environmental impact is still ongoing while submitting this abstract. We obtained a number of compound feeds (over 30) of which we have the exact composition, and we are analysing them in order to find the minimal required information. The results will show us how far off the current impact assessments are due to the use of categories instead of precise assessments.

4. Conclusions

The share of feed in the total carbon footprint of animal based products can be as high as 75% and is not well accounted for in the current tools. The major bottleneck is a lack of precise data from the feed companies. This work has contributed to a better approximation by collaborating with the national Feed Associaton

1.02.T-04 Use of LCA as a Tool for Sustainable Product Development: A Chemical Industry Example

Ravinder Menon, Afton Chemical Corporation (NewMarket Corporation); Jean-Philippe Neveu, Afton Chemical; Benn Heatley, Afton Chemical.

Background
Afton Chemical is a global manufacturer of lubricant and fuel additives. We have been conducting LCA (life cycle assessment) of our products since 2011. Initially, we hired consultants to do LCA but as the number of customer requests increased, this became expensive and time-consuming. After some brainstorming, we developed with a consultant, the LCAT (Life Cycle assessment Automation Tool), which we have been using since Nov-2021. LCAT has gone through critical review recently and been validated against ISO 14067, as well as the TfS (Together for Sustainability) PCF (Product Carbon Footprint) guidelines for the chemical industry.

Besides using it for responding to external customer requests, we have also started using LCAT for screening new R&D formulations. This presentation describes an example, where close collaboration between our R&D and LCA teams led to the development of a sustainable next generation product with 41% lower PCF.

Methods
The formulations being developed by R&D were screened by the internal LCA team using the scenario modeling functionality in LCAT, and PCF results provided promptly. This helped the researchers refine the formulations for carbon efficiency, while making sure that the performance requirements were met. As the manufacturing site was not yet known, the same site was used as for the incumbent, which allowed for an even comparison. This was doen iteratively with R&D, until the right formulation (lowest PCF and met all performance requirements) was identified.

Results
The formulation selected as the next-gen product had 41% lower PCF than the incumbent product, and met all required performance criteria as well.

Conclusions

Afton Chemical co-developed the LCAT system for conducting LCA efficiently. It is our standard tool for conducting LCA and providing results to our customers. Recently however, we have also been using LCAT for internal screening and product development purposes. This presentation is about an example where LCAT was used in the development of a sustainable next-generation fuel additive, by screening candidate R&D formulations for carbon efficiency and help in the selection of the final candidate that was commercialized. This led to an improved product with a 41% lower PCF, a major achievement in our journey toward developing products that lower emissions in the life cycle and help industry progress toward their sustainability goals.

1.02.T-05 Electric Motors: A Parametrized Life Cycle Inventory Model Bolstered by Interdisciplinary Primary Data

Mohamed Sahaoui, Mines Paris - PSL; Mathilde Marchand-Lasserre, MINES Paris – PSL University; Pierre Arnaud, MINES Paris – PSL University; Sébastien Joannès, MINES Paris – PSL University; Paula Pérez-López, MINES Paris – PSL University.

In the context of the energy transition, the "electrical vector" is a key player, with rotating electrical machines such as motors and alternators playing a central role. The filament windings, which constitute the "active" element of these machines, represent a significant concern, as they contribute to nearly 30% of the machine failures, which are primarily due to insulation issues. This not only limits the system's operational lifetime but also presents a challenge to the sustainable management of resources. Consequently, within the context of eco-design of electric machines it becomes imperative to improve our understanding of winding lifetime. The identification of the fundamental design and usage parameters can facilitate the environmental optimization of these rotating machines, as well as the characterization of the associated uncertainties. This work employs an interdisciplinary approach that integrates insights from mechanical & materials sciences with those from environmental sciences. The objective is to present a procedure to identify the influential motor design and usage parameters affecting environmental impacts and to discuss the potential advantages of a combined approach for their determination. A parametric Life Cycle Analysis (LCA) model enables the calculation of materials and energy quantities based on a set of architectural and usage entry parameters of the electric motor. This type of modeling enables the handling of uncertainties associated with each parameter. These uncertainties will propagate to the bill of materials and energy up to the final impact results. The parameterized model allows for the identification of design and usage parameters driving the final environmental impacts through sensitivity analysis. As motor lifetime stands out as a significant factor influencing impacts, mechanical testing and materials sciences provide a reliable means of determining the lifetime behavior of electric motors as a function of design and usage parameters. A physical model that is empirically determined and that relates motor design and usage parameters to lifetime is presented. The model is then employed to calculate the lifetime within a parameterized LCA model of an electric motor. This procedure enables a more end-use oriented determination of material and energy quantities across the life cycle of the electric motors, thus allowing more accurate impact calculations.

1.02.P - Collecting Internal and Collaborative Data for LCA – Securing Availability and Quality

1.02.P-Tu001 Environmental Evaluation of Automatic Washing Machine

Anastasiia Timofeeva, University of Bologna; Giampaolo Campana, University of Bologna; Maurizio Fiorini, University of Bologna.

Multifunctional automatic solution allows to wash components and machine parts of different size and volumes in completely automatic mode for pharmaceutical packaging line. The environmental impact of industrial washing machines is a significant concern, especially considering their extensive use in automation sectors.

This study aims to conduct a comprehensive Life Cycle Assessment (LCA) of automatic washing machines, with a specific focus on Life Cycle Inventory (LCI) phase. The objective is to quantify the environmental impacts associated with material extraction, production processes, transportation, usage, and disposal thereby identifying critical areas for improvement.

The LCA is conducted in accordance with ISO 14040 and ISO 14044 standards, ensuring a standardized approach to environmental impact assessment. The study adopts a Cradle-to-Grave boundary, encompassing the impacts from material extraction, production, transportation, use stages and disposal. The ReCiPe 2016 method is utilized for the Life Cycle Impact Assessment (LCIA) and covering key eco-indicators. The manufacturer of washing machine has provided the primary data and Ecoinvent database provides the rest necessary background data, while SimaPro software is employed for modeling and analysis.

The preliminary findings demonstrate that the most significant environmental impacts arise from the usage phase, particularly due to the energy-intensive processes. Transportation also contributes notably to the overall impact, though to a lesser extent. The usage of high-impact materials such as stainless steel and various chemicals as alkaline detergent in manufacturing further exacerbates the environmental footprint.

This study underscores the importance of targeted improvements in the recommendation for usage equipment, production processes and material selection to mitigate the environmental impacts of industrial washing machines. By optimizing these areas, manufacturers and customers can significantly reduce the ecological footprint of their products. The findings provide a key reference point for future developments and regulatory policies aimed at enhancing the sustainability of industrial equipment.

1.02.P-Tu002 Life Cycle Assessment (LCA) of Graphene Production: A Review of Data Collection Methods and Challenges in building Life Cycle Inventory (LCI)

Agata Costanzo, University of Padova and Scuola Superiore Sant'Anna; Monia Niero, Sant'Anna School of Advanced Studies; Marco Frey, Sant'Anna School of Advanced Studies.

Life Cycle Inventory (LCI) is unanimously considered the most challenging part of conducting a Life Cycle Assessment (LCA) study. This happens to be particularly true when novel technological processes in the field of nanomaterials have to be modelled. With this contribution, we present an LCI-oriented literature review regarding LCA on graphene production processes, aiming to illustrate the strengths and weaknesses of employed data collection methods, and lay the foundation for developing reliable LCIs for novel graphene production processes. The literature review was conducted on Scopus using the combination of the following keywords: "life cycle assessment OR LCA AND graphene", "life cycle assessment OR LCA AND graphene AND production", and "life cycle assessment OR LCA AND graphene production". Our focus was on papers explicitly addressing graphene production processes which were categorized based on seven parameters: production method, functional unit (FU), system boundaries, data sources, databases, Life Cycle Impact Assessment (LCIA) method, and impact categories. 16 papers were selected and systematically analyzed, focusing on how the LCI was conducted, where data were searched, and the underlying assumptions. The reviewed papers encompassed various graphene production methods, ranging from ultrasonication and chemical reduction to thermal exfoliation and biotechnological approaches. FU varied as well according to the analyzed production methods; we distinguish between mass-based and surface-based FU. System boundaries, data sources, databases, and process maturity also showed high diversity, influencing how the LCIs were constructed. Inventories were built using data from patents, literature reviews, laboratory experiments, interviews, and a combination of these sources. Our analysis focused on strengths and weaknesses in the data collection methods. Strengths included detailed process descriptions and the use of high-quality primary data, while weaknesses encompassed reliance on assumptions due to data gaps and variability in system boundary definitions. This contribution highlights the need for standardized approaches to LCI in graphene production LCA studies. It underscores the importance of transparent data collection, robust assumptions, and comprehensive system boundary definitions for developing reliable LCIs, ensuring comparable LCA results, and facilitating informed decision-making.

1.02.P-Tu003 How the Use of Different Databases Affects the Comparability of Life Cycle Assessment Results of Fiber Reinforced Polymer Composites
Karina Kroos, German Aerospace Center (DLR); Sabrina Diniz, German Aerospace Center (DLR); Jens Bachmann, German Aerospace Center (DLR); Steffen Opitz, German Aerospace Center (DLR).

Sustainability gained significant popularity these days and in order to support decision making towards this, Life Cycle Assessment (LCA) is becoming increasingly important. However, the full potential of these assessments can only be unlocked if the comparability of the results is guaranteed. Databases such as Ecoinvent and Sphera are the backbone of LCA models and they have a crucial impact on the results. Usually, foreground data for a product or service is limited to a small range of known activities in a gate-to-gate perspective where primary data can be obtained. For a more complete view on the potential environmental impacts, it is necessary to extend the model with the upstream activities back to the extraction of natural resources to gain a cradle-to-gate or a full life cycle perspective (cradle-to-grave/cradle).
When talking about the comparability of results, it is important to address the issue of uncertainties. These exist in every phase of LCA and are too many to point out individually here. The existence of different databases, intended to provide support in LCA, are just a part of this bigger picture. It is therefore not only important to know which databases are utilized for analysis in order to be aware of their differences and resulting uncertainties in this particular context, but also to understand their differences in more detail. One important question is if it is valid to mix different databases to fill gaps in the Life Cycle Inventory.

This study intends to make potential differences of databases more tangible. To achieve this the model for producing a typical fiber reinforced polymer (FRP) product made out of glass fibers and epoxy resin is created based on DLRs expertise in the manufacturing of lightweight systems. The foreground data for the selected product is fed with background data from different existing databases. The results obtained are finally used to unveil the differences for the sixteen categories of the EF3.1 methodology and to identify to what extent the comparability is affected. Additionally, the study gives an overview of the main uncertainty contributors in this use case as a contribution towards a transparent decision making.

1.02.P-Tu004 Life Cycle Assessment (Lca) Methodology to Address the Environmental Sustainability of New Materials Developed and Used to Treat Wastewater
Dimitrios Ziotas, University of Bologna.

Background and Purpose:
Within the IN2AQUAS project, this research aims to employ Life Cycle Assessment (LCA) methodologies to assess the environmental sustainability of innovative materials and processes for wastewater treatment. Our focus lies in assessing the synthesis and application of these materials, particularly carbon quantum dots (CQDs), humic substances (HS) and humic-like substances (HLS). By defining the complicated environmental footprint of these materials, the aim will be to offer scientifically grounded insights into optimizing wastewater treatment processes.

Methods:
Collaborative efforts within the IN2AQUAS consortium enable us to rely on primary data to model a comprehensive Life Cycle Inventory (LCI). Utilizing LCA frameworks and software, our methodology involves a systematic evaluation of the synthesis procedure and application scenarios of synthesized material. This approach ensures reliable assessments of the environmental impacts associated with each stage of material life cycle, facilitating well founded decision-making and technological advancement. While awaiting data, a Life Cycle Costing Analysis (LCC) has been conducted on a wastewater treatment research, creating a basis for future economic assessments.

Expected Results:
Anticipated outcomes encompass a comprehensive understanding of the environmental impacts in utilizing synthesized material in wastewater treatment. By quantifying key impact categories such as greenhouse gas emissions, energy consumption, and resource depletion, we aim to pinpoint critical areas for efficiency enhancement and environmental preservation. Furthermore, comparative analyses with conventional treatment methods will indicate the relative advantages of employing novel materials, informing future research directions.

Conclusions:
The research is poised to catalyze significant advancements in sustainable wastewater treatment practices. Through scientific inquiry and collaboration, the aim is to establish evidence-based guidelines for integrating novel materials into wastewater treatment infrastructure towards a more sustainable future. By leveraging LCA methodology, this research aims to establish a more sustainable approach for wastewater treatment and minimize environmental impacts.

1.02.P-Tu005 Life Cycle Assessment in Paper and Pulp Industry: Addressing the Data Exchange Challenges
Hansani Perera, Aalto University; Udayanto Atmojo, Aalto University; Valeriy Vyatkin, Aalto University.

Background and Purpose:
The paper and pulp industry faces significant environmental challenges, including air pollution, greenhouse gas emissions, and wastewater discharge, necessitating sustainable operations. Regulatory bodies impose stringent measures to mitigate these impacts, compelling the industry to adopt sustainable practices and technologies. Life Cycle Assessment (LCA) models are crucial for evaluating environmental impacts and aiding sustainable manufacturing decisions. However, organisations prioritise the confidentiality of sensitive data, hindering collaborative LCA efforts. This study addresses the need for enhancing data confidentiality,

tamper-proof data transfer, and ensuring data sovereignty using Secure Multi-Party Computation (SMPC) and data spaces.

Methods:
The study involves the development of a data space for sharing information among organisations using a standardised data model. Open-source components provided by the International Data Spaces Association (IDSA) have been utilised in creating this data space. The fundamental solution comprises a broker responsible for holding metadata of the published data, a certification authority to verify each organisation, an access management service, and data space connectors to link the data resources of organisations with the data space. The transfer of data is secured using Secure Socket Layer (SSL). Additionally, SMPC algorithms need to be implemented atop the data space to compute functions over inputs while maintaining the privacy of those inputs. The calculated results will be verified using zero-knowledge proofs (ZKP).

Results/Hypothesis:
The integration of SMPC and data spaces within a LCA platform will significantly enhance data confidentiality and data sovereignty, enabling more accurate and collaborative LCA calculations without exposing sensitive information. By leveraging cryptographic techniques, such as ZKP and SSL, the proposed platform will ensure trust in computations and the security of data transfer. This will promote sustainable practices across the supply chain by facilitating tamper-proof data sharing while preserving the privacy of proprietary data.

Conclusions:
The proposed framework for privacy-preserving LCA in the paper and pulp industry enhances sustainability by facilitating accurate LCA calculations without necessitating organisations to share their sensitive data with one another. This ensures that all participants can contribute their data transparently, supporting accurate and transparent LCA assessments while safeguarding sensitive information within the value chain.

1.03 - Hybrid LCAs for a Circular Economy: The Added Value of Combined Methodologies

1.03.T-02 Using Multi-Regional Input-Output Models for Absolute Environmental Sustainability Assessments of Industries
Abdur-Rahman Ali, Technische Universität Braunschweig; Steffen Blömeke, Technische Universität Braunschweig (IWF); Christoph Herrrmann, Technische Universität Braunschweig (IWF).

There is an urgent need to limit the environmental impacts of products and services to stay within environmental carrying capacities. Concepts such as planetary boundaries, IPCC carbon budgets, and science-based targets have attempted to quantify these capacities. They delineate a safe operating space (SOS) at global and regional levels for products, sectors, and companies. Sharing principles are needed to downscale the SOS to specific industries and products. The most commonly used metrics for implementing these sharing principles are based on environmental emissions (grandfathering) and monetary terms. Recent studies have developed methods to downscale the environmental carrying capacities of specific products using sharing principles and subsequently assess if the products' impacts are higher or lower than their assigned share of the safe operating space (aSoSOS). However, there is a lack of consistent sources for the emission (grandfathering) and monetary data needed to derive the aSoSOS. Using environmentally extended multi-regional input-output (EE-MRIO) models, such as Exiobase 3, can provide a consistent source of emission and monetary data for performing absolute environmental sustainability assessments.

In this study, we derive aSoSOS for the 163 industries and 200 products in 44 countries and 5 regions provided in Exiobase 3. We use the derived shares to determine specific environmental impact budgets for different industries. We then compare the environmental impacts of the industries to their aSoSOS to identify those requiring urgent mitigation actions. Our results also indicate countries performing well in specific industries and vice versa. For instance, in the "Manufacture of motor vehicles, trailers, and semi-trailers" industry, 26 of the 49 countries and regions have ratio values higher than one. In contrast, in the "Real estate activities" industry, only 4 of the 49 countries and regions have ratio values higher than one. Finally, we discuss the challenges and limitations of extending this approach to companies and products within the considered industries and identify future research needs.

1.03.T-03 Combined Assessment of Planetary Boundary Exceedance and Life Cycle Damage of Global Consumption
Santiago Acosta-Izquierdo, Technical University of Denmark (DTU); Michael Hauschild, Technical University Denmark; Olivier Jolliet, Technical University Denmark.

LCA has been developed for determining impacts of products and services over their entire life cycle, assessing damages on human health (HH), ecosystem quality (EQ) and natural resources, with a focus on relative improvements of products. In parallel, Absolute Environmental Sustainability Assessments (AESA) assess the absolute sustainability performances of products and compare their impacts with limits fixed by planetary boundaries. Both frameworks continue evolving separately and there is a need for combining these approaches for sound decision making.

This study presents a framework to consistently perform a combined assessment of absolute sustainability and damages, to be simultaneously considered by decision-makers, and apply it to evaluate the impacts of world overall consumption. Using an Environmentally Extended Multi-Regional Input-Output Model to evaluate elementary flows associated with global consumption, Impact World+ to assess the corresponding Life Cycle Damages, and sustainable boundaries aligned with the LCIA metrics, we determine damage and absolute sustainability status for 18 specific impact categories affecting ´HH, and EQ areas of protection (AoP). An area-based graphic, enables us to visualize for each AoP both the exceedance fold of each impact category specific planetary boundary (Y-axis), and the corresponding damages (X-axis and total area).

Damages associated with global consumption are exceeding global sustainable levels for 50% and 62,5% of the HH and EQ impact categories. The exceedance does not directly relates to the damage per se, and are complementary representations. For example, the global consumption exceeds climate change planetary boundary by a factor 30, with a damage of 9.2E+7 DALY/y, whereas it exceeds the fine particulate boundary by a lower factor of 10, but with a higher impact of 1.3E+8 DALY/y. Similar contrasting tendencies are observed for ecosystem quality impacts contrasting high impacts and high exceedance factors associated with land use (2.6E+13 PDF-m2-y/y; exceedance fold of 39) and climate change (2.0E+13 PDF-m2-y/y; exceedance fold of 30). In contrast terrestrial acidification is below planetary boundaries (exceedance factor of 0.7) but still has a substantial impact (4.8E+12, PDF-m2-y/y). In conclusion, it is crucial to consider both planetary boundary and level of damages, damages being able to provide science-based weighting to the respective planetary boundaries in different impact categories.

1.03.T-04 Recalibrating the European Aluminium Sector towards a Circular Economy Transition: An Integrated Assessment
Paola Federica Albizzati, European Commission - Joint Research Centre (JRC); Anna M. Walker, Joint Research Centre, European Commission; Pelayo García-Gutiérrez, Joint Research Centre, European Commission; Davide Tonini, Joint Research Centre, European Commission.

In the European Union (EU), the transition to a Circular Economy (CE) is paramount for achieving the objectives of the EU Green Deal. However, current legislative efforts to improve material circularity remain ineffective. Thus, a recalibration of the CE policy framework in the EU is required to accelerate this transition. To provide guidance, the Joint Research Centre launched the exploratory project RecalibrateCE, aiming at assisting sound decision-making on effective CE policies. It focuses on four carbon intensive industry sectors in the EU, exemplifying first results, here, on the aluminium sector. The project aim is i) to develop a methodology to assess CE interventions, and ii) to assess the contribution of different levers (interventions) to the performance and sustainability of the aluminium sector. The research comprises a combination of methods that can be applied to all industrial sectors and enable an integrated assessment of future policy interventions. These include 1) Material Flow Analysis of the sector, 2) the identification of circularity levers and their effectiveness based on literature, 3) prospective Life Cycle Assessment (LCA) and Life Cycle Costing, (4) Environmentally-Extended Input-Output (EEIO) analysis, 5) economic modelling to capture potential macroeconomic and rebound effects that cannot be captured with the other methods, and finally 6) a sensitivity analysis based on four normative scenarios of the future. The outlined method allows to identify circularity levers that enable the highest material circularity at the lowest environmental and socio-economic impacts, while supporting the development of policy options. The results show the quantification of the implementation of the levers on both current and future material flows and the impacts of these flows from an environmental and economic perspective. Also, novel methodological insights, not encountered in literature before, are given e.g., the definition of the sector system boundaries and functional unit. The interactions and complementarities between bottom-up LCA and top-down EEIO analyses are discussed, as well as the pros and cons of using one method or the other and how to combine the effects of the levers and their interactions. Concluding, the new insights into methodological aspects and anticipated effects of future CE interventions in this research facilitate the development of effective policy options and open new perspectives in the field of quantitative assessments.

1.03.T-05 The Circular Industrial Transformation System (CITS) Model - Assessing the Environmental Impact of Circular Strategies
Sietske Lensen, TNO; Anna Schwarz, TNO; Paul Stegman, TNO; Sjoerd Herlaar, TNO; Toon van Harmelen, TNO.

The state-of-the-art global economic system can be identified as linear and fossil-based. As a solution to the increase in material and energy requirements, the concept of circular economy was introduced to support sustainable development and reduce environmental pressure. Although circular economy and reduced environmental impact are often used within similar context, circular strategies may result in environmental trade-offs as well, such as an increase in energy demand to keep materials in the loop. To assess the environmental and financial consequences of circularity measures in industries over time, we integrated Dynamic Stock Flow Modelling, Material Flow Analysis and prospective Life Cycle Assessment in the Circular Industrial Transformation model (CITS). CITS uses a combination of lifetime and product compositions data, material flows, life cycle inventory datasets and background scenario data from integrated assessment models. To illustrate the potential of the CITS model, the transition towards electric vehicles for the automotive sector in Germany was assessed with circular economy interventions and climate policies. Results show the circularity of the system, as well as individual product & material demand, annual production needs, and waste generation over time. Insight were given over the full value chain, resulting in insights at capacity requirements. Calculations of the systemic environmental impacts show that mitigation, such as climate policies for energy, should be aligned with electrification of the automotive passenger fleet. Results of the automotive case study aligned with traditional LCAs of automotive vehicles, but highlights the importance of the system perspective in the transition towards electric vehicles and the potential of circular interventions. The model framework is flexible and can be applied broadly to assess the effects of circularity measures on materials and impacts of any system.

1.03.P - Hybrid LCAs for a Circular Economy: The Added Value of Combined Methodologies

1.03.P-Tu006 Novel Diagrammatic Notation for Hybrid Life-Cycle Assessment
Michael Weinold, Paul Scherrer Institute (PSI).

At least four distinct methods for hybrid life-cycle assessment (HLCA) are now widely recognized in literature. Recent reviews of these methods include Islam et al. (2016) and Crawford et al. (2018).

Unfortunately, the specific advantages and challenges of these methods have not been thoroughly investigated. Therefore, no clear recommendation on their application was provided in these recent review publications.

During recent attempts at implementing these methods into the Brighway open-source life-cycle assessment framework, I found that a unified diagrammatic notation greatly aides not only in the illustration of different HLCA methods, but in understanding their computational structure - and therefore their underlying differences.

My novel diagrammatic notation allows the visualization of combining a process-based product system with an input-output-table based sectoral system. It further shows directly several key mathematical features of HLCA, including:
-the correspondence matrix
-structural path analysis approaches
-various different instances of double-counting
-the direct effect of double-counting correction methods

My work presents a significant improvement over previous attempts to visualize hybrid life-cycle inventory systems byTreloar (1998),Suh and Huppes (2005),Cruze (2013),Crawford et al. (2018) and Strømman (2019).

Besides the legend for my novel diagrammatic notation, my poster will provide elegant and intuitive visual proof that the “path-exchange hybrid method” originally proposed by Lenzen and Crawford in 2009 is mathematically equivalent to the “integrated hybrid” method proposed by Suh in 2004. Since the corresponding formal proof by means of linear algebra is an involved undertaking, this will illustrate the usefulness of my novel visualization system.

1.03.P-Tu007 Material-Energy Efficiency Through Input-Output Analysis: Italian Case Study in Wood Furniture Sector

Elena Battiston, University of Padova.

Background: In the last decade, the European Union has promoted methodologies for measuring and communicating environmental performance from a life cycle perspective of products and organizations. The Organizational Life Cycle Assessment method is slowly spreading: one of the possible obstacles to overcome is input-output analysis. Collecting reliable data and applying rigorous choices discourage companies from starting the analysis.

Purpose: This research reports the experience done by Italian company leader in wood furniture sector, located in the north-east of Italy. The objective is to support the company in reducing resource consumption and better managing the waste produced.

Methods: The evaluation is conducted also with reference to material flow cost accounting regulated by ISO 14051. System boundaries are defined in accordance with organizational life cycle approach, focusing on "gate to gate" analysis. Identification and quantification of inputs and outputs of resources (materials, energy, water, components, etc.) and emissions (air, water, soil, waste) have been obtained with reference to 2022. Primary data collection has been done through inspections, interviews and consultation of documents; secondary data has been added from scientific literature.

Results: Firstly, flow diagram is the qualitative result that highlights the types of resources that enter and exit the process phases. Secondly, the input-output analysis made it possible to quantify waste and energy consumption. Considering the 2022 production, the largest quantity of waste is wood waste (95% of the total). Other relevant environmental aspects are the consumption of electricity for the functioning of 122 machines, and the production of paper and plastic waste.

Conclusions: The input-output analysis allows to understand environmental performance of company, based on type and quantity of materials, resources, and emissions correlated production activities. Effective solutions have been identified to improve sustainability of production processes: waste minimization, recovery and recycling of waste, and energy efficiency are the main important challenges.

1.03.P-Tu008 Combination of Spend Based and Activity Based Approaches for Efficiently Calculating Global Corporate Carbon Footprint of Organizations

Marco Scherer, iPoint-Systems GmbH; Kaja Mol, iPoint-systems gmbh; Sabrina Neugebauer, iPoint-systems gmbh.

Against the background of increasing global climate challenges, accurately calculating the Corporate Carbon Footprint of organizations has become a critical task for multi-national organizations. Traditionally, activity-based LCA methods have been the standard for obtaining accurate results for different environmental impacts. However, the nature of these methods, require extensive data collection, model construction, and thus significant resources for both time and money. Therefore, this study introduces an approach that synergizes the traditional activity-based carbon footprint calculation with a spend-based approach resulting from Input/Output analyses (often referred to as hybrid LCA). This approach will enhance the practicability and efficiency of carbon footprint calculations for individual products and entire companies, providing a comprehensive framework that leverages both detailed and macro-level data for environmental impact assessment.

We conduct a study in collaboration with a leading international organization of outdoor equipment / mobile living, known for its diverse product portfolio. The initial phase involves the analysis of the company's existing data repositories to evaluate the availability and quality of the required information. Subsequently, we develop a data lake, designed to facilitate the automated calculation of both Corporate Carbon Footprints and Product Carbon Footprints . This system is designed to seamlessly incorporate both activity-based and spend-based approaches, thereby harnessing the strengths of each methodology.

Preliminary findings indicate a general alignment between the results derived from the activity-based and spend-based methodologies, suggesting the viability of the combined approach in accurately estimating environmental impacts. However, further analysis is necessary to validate the initial findings. Furthermore, we aim to refine our automated calculation method (such as Rest API configuration or Automated mapping logics) and highlight the key aspects and prerequisites for its successful implementation. The study contributes a practical case study to the field of hybrid LCA focusing on carbon footprint calculations where there seems to be no final consensus on the benefits and limitations by offering a compelling case for its adoption by one international organization aiming to mitigate their overall environmental impact.

1.04 - Open-Data and Reproducibility: Towards Replicable, Reliable and Transparent LCA Practices

1.04.T-01 Data Sharing – Challenges and Opportunities for LCA

Massimo Pizzol, Aalborg University; Agneta Ghose, Aalborg University.

There is a critical need for effective data management in Life Cycle Assessment (LCA) practices. This study emphasizes the challenges posed by isolated datasets and the lack of standardized sharing protocols. It underscores the importance of FAIR data principles—Findable, Accessible, Interoperable, and Re-usable—and the collective responsibility in implementing these within the LCA domain. The research reviews existing infrastructure for data sharing such as ISO standards, Data Management Plans, and data repositories to understand their role in supporting FAIR data sharing. Finally the study introduces a systematic workflow for FAIR data sharing, exemplified by its application in the Horizon Europe ALIGNED project.

1.04.T-02 Beyond Data Sharing: Addressing the Reproducibility Challenge in LCIA through a Software-Agnostic DSL

Tomás Navarrete Gutiérrez, Luxembourg Institute of Science and Technology; Gustavo LARREA-GALLEGOS, Luxembourg Institute of Science and Technology.

We introduce an early-stage Domain-Specific Language (DSL) prototype aimed at enhancing reproducibility in sustainability assessments, particularly in building life-cycle inventories (LCI) for life-cycle assessment (LCA). The prototype addresses the critical need for transparent data representation in LCA, tackling challenges in reproducibility and collaboration.

The DSL is designed to facilitate transparent, reproducible sustainability evaluations, offering a framework for researchers and practitioners to analyze and compare studies. By distinguishing between data-centric challenges and reproducibility issues, the DSL aims to enable clear communication of LCA inventory creation, promoting openness and accountability.

A novel feature of this software-agnostic DSL is its independence from specific LCA software, allowing researchers to share and reproduce LCI data across various platforms. 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.

This submission intends to stimulate discussion within the environmental informatics community on the nuanced challenges of reproducibility in LCA. By presenting a solution that transcends data-centric concerns, this paper contributes to the ongoing dialogue surrounding the development of methodologies that prioritize the transparent sharing of actions to achieve reproducible LCA.
A demonstration using the Brightway LCA framework highlights the DSL's practical application, emphasizing the syntax-software separation. 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.

This work aims to stimulate discussion on reproducibility challenges in LCA within the environmental informatics community. By presenting a solution that transcends data-centric issues, it contributes to the ongoing dialogue on methodologies that prioritize transparent sharing of actions for reproducible LCA.

While the DSL prototype is in its early stages, it lays the groundwork for future advancements in sustainability assessment methodologies. Future work could address the inclusion of parameters, data ingestion, contribution analysis, uncertainty evaluation, and data quality through a modularized re-implementation of the DSL to incrementally improve its syntax.

1.04.T-03 Reproducibility Starts Before the Project: A Framework for Harmonised Data Collection in LCA

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Background and Purpose:
LCA is a powerful, albeit complex, tool due to 1) the multiple steps and accompanying parameters associated with each stage of a LCA) and 2) the need for data from diverse fields of study to build a robust and holistic life cycle inventory (LCI), foster development in life cycle impact assessment (LCIA) methodology and support research claims derived from LCA interpretation. The present work describes a framework called information flow analysis (IFA) and describes how it can allow for the inclusion of open data such that reproducibility can be achieved, despite the complex and holistic nature of LCA.

Method
Using the principals of MFA, all relevant direct and indirect flows of information can be mapped in the so-called IFA where rather than processes, fields of study are included as boxes and rather than flows of materials, flows of information (qualitative and quantitative) are included as arrows that connect each field of study.

Conclusion
It is rare that all relevant flows of information are known or communicated such that these data sets can be obtained because there lack activities in today's research that focus entirely on defining data gaps and needs in this way prior to experimentation, data collection, and analysis. IFA could be a tool to help define and communicate data and information flows in a concrete format such that other researchers that aim to build upon existing studies can follow similar protocols in data acquisition and avoid producing results that cannot be compared to other previous, current or future studies.

1.04.T-04 A New Paradigm for Findable, Maintainable, and Flexible Open Industrial Ecology Databases

Chris Mutel, Cauldron Solutions; João Gonçalves, Cauldron Solutions.

Existing LCA databases and methods do not support open, science-based debates or build public trust. We know that a better path is possible - projects like Climate TRACE show that our challenge is now handling data abundance, and that we can integrate complex models. Our ambition is to make this progress broadly available.
As a first principle, the data, code, documentation, and results must all be free and open source. We have a moral obligation to make this information accessible to everyone. Being open is also the only way to get large-scale participation, feedback, and data sharing. Openness also extends to governance - people need a vote and an ownership stake in a community-wide effort.
Such an effort requires three major changes. First, we need a consensus taxonomy. Insane amounts of work are currently spent matching "steel, chromium steel 18/8" to "EN 1.4301" to "AISI 304" to "stainless steel". We should only use terms from existing standards and semantic vocabularies, and work with those standards when changes are needed.
Second, we need a framework for inventory models and data stores. The current way we build unit process datasets is not maintainable, adaptable, or interpretable at scale. There is a better way - a clean separation of data with logic encapsulated in models. Inventory models are computational objects embedding the logical rules explaining complex relationships between inputs and outputs. Models can search in for the data it needs on demand, and the search can be context-aware, looking only for the time, place, or specific product needed. Gap-filling models can also be used to fill in missing values or to extrapolate across time and space.
Finally, any model of our ever-changing world will be incomplete. To ensure the highest possible quality, validation will be built into every step of the data pipeline - for example, models will include acceptable ranges for their parameters, and unit process results will be scaled up to regional or global totals and compared with statistics or measured results. Such validation checks will at first be manual, but as the database grows they can be increasingly derived automatically from the available data. Each model run will include both data lineage and a quantitative estimates of uncertainty and data quality. The datasets and models which have the largest systematic impacts or lowest overall quality will then be published as an open prioritisation list.

1.04.T-05 TianGong Database: An Open-Source Life Cycle Unit Process Database for China's Industrial System

Jianchuan Qi, Tsinghua University; Ming Xu, Tsinghua University; Nan Li, Tsinghua University; Huimin Chang, Tsinghua University; Xiaohui Lu, Tsinghua University.

China plays a pivotal role in global manufacturing and sustainability efforts, yet Life Cycle Assessment (LCA) studies are hindered by inadequate region-specific data and outdated datasets. To address these challenges, we introduce the TianGong Database, an open-source ILCD entry-level LCA database incorporating the EF 3.1 reference dataset, specifically tailored to the Chinese industrial system. The database encompasses over 4000 datasets, with high spatial resolution down to the city level and extensive sectoral coverage. Developed through a community-driven approach, TianGong ensures transparency, traceability, and international standard compliance, and is completely open and free. This robust resource enhances the accuracy and reliability of LCA studies, supporting informed decision-making for resource efficiency and carbon reduction. The TianGong Database significantly advances

LCA data quality, benefiting both China's sustainability goals and global supply chain assessments, promoting a more sustainable and circular economy.

1.04.P - Open-Data and Reproducibility: Towards Replicable, Reliable and Transparent LCA Practices

1.04.P-We001 Mapping the Global Distribution of Supply Chains Using Customs Data

Chunshuo Ge, Chalmers University of Technology ; Björn Sandén, Chalmers University of Technology.

Life Cycle Assessment (LCA) as a crucial methodology for comprehensively evaluating the environmental impacts of products, processes, and services by accounting for their entire lifecycle typically requires intensive amount of data input. Variations in data input, such as data sources, geographic contexts and temporal factors directly influence the validity of outcomes and conclusions. This data sensitivity nature makes data collection a challenging aspect of LCA studies. This challenge is further compounded by two key aspects: time, referring to the temporal lag between data collection, study execution, and the actual timeframe being investigated; and space, referring to the complexities of the supply chain across different geographic locations.

This study focuses on addressing the spatial challenge by applying customs data in international trade databases. The international customs data is advantageous as it is regularly updated, versatile, open-access and of high reliability. Annually, around 160 countries and territories report their trades with international partners directly to the United Nations Statistics Division. Through additional data processing, such as mirroring, the developed international trade database can expand its coverage to encompass over 200 countries and include 5,000 products (Gaulier & Zignago, 2010). By analysing the export and import flows of a certain product connecting all involved countries or territories, a global overview of net production or consumption of this product can be derived. More ideally, by analysing the flows of product components and subcomponents, a supply chain across phases of raw material supply, manufacture, and product use can be depicted. The derived results can be used in the inventory analysis. When a product is sourced from the global market, instead of selecting one specific country or firm as origin, with its related emission profile, a global distribution can be used.

Gaulier, G., & Zignago, S. (2010). BACI: International Trade Database at the Product-Level. The 1994-2007 Version (No. 2010–23). http://www.cepii.fr/CEPII/fr/publications/wp/abstract.asp?NoDoc=2726

1.04.P-We002 Process Model-Based Life Cycle Assessment: Framework, Strengths, and Consistency

Heikki Lappalainen, Aalto University; Benjamin P. Wilson, Aalto University; Mari Lundström, Aalto University.

Process modelling can be used to provide life cycle inventory data from processes for which primary data is not available. The strengths of such process simulation-based life cycle assessment (LCA) are that even non-existing processes can be explored and that various scenarios can be investigated simultaneously with relatively low effort. Moreover, such process models provide detailed mass and energy balances, which are often missing in life cycle inventories. However, some difficulties exist in ensuring and evaluating the data quality and consistency from such process models. Also, any standardized data pipeline or workflow practices do not exist, which decreases the transparency of the whole framework.

Here we discuss some of the issues related to process model-based LCA and also the strengths of the combined framework compared to traditional LCA. We present a case study of a hydrometallurgical process modelled in HSC Sim and give examples of the LCI and the factors that affect its quality. The study is related to RESPECT project, which explores lithium-ion battery recycling processes and methods. We discuss different aspects of the workflow, data formats, and the integration of a process model software (HSC Sim) and an LCA software (openLCA). Also, we give examples of the benefits of process models in calculating the scope 1 emissions in HSC Sim using thermodynamic equilibria. Finally, we make some remarks about the standardization of methodology in process model-based LCA and the role of sensitivity analysis in estimating the data reliability.

1.04.P-We003 A Protocol Prototype for Enhancing the Reproducibility and Transparency in Life Cycle Inventory Building

Gustavo Larrea-Gallegos, Luxembourg Institute of Science and Technology; Tomás Navarrete Gutiérrez, Luxembourg Institute of Science and Technology.

Nowadays, Life Cycle Assessment (LCA) steps, such as the Life Cycle Inventory (LCI) building, rely more and more on computational methods to address complex scientific inquiries. This occurs because current LCI practices go beyond the mere accounting of static supply chain models since they require to integrate LCI calculations with distinct computational operations. New modelling steps like data-driven predictive pipelines have been incorporated into LCA through novel workflows that include methods that stem from foreign domains. This sophistication of modelling workflows comes with a price since it adds another layer of difficulty when it respects to providing a transparent and reproducible description of the LCA study. While the necessity of incorporating transparency principles in LCA has been discussed, not much attention has been provided to the lack of reusability and reproducibility of the methodologies and calculation workflows that are used in the LCI step.

To address this limitation, we developed a novel protocol prototype designed to enhance the transparency and reproducibility of programmatic LCA workflows. This protocol consists on guidelines and checkpoints for LCA practitioners that can facilitate the generation of reproducible research outputs. It was built following current practices used in other research fields in combination with the needs of programmatic LCA. Moreover, to bootstrap the adoption of this protocol, we developed a python tool called bw2scaffold, which is an LCA project template generator designed to facilitate the organization and modeling of projects that use the brightway software ecosystem. bw2scaffold package was designed to create a recommended folder structure, code snippets, and documentation templates that comply with the protocol checkpoints. We identified that protocol compliance can provide benefits at different stages of maturity of an LCA study. It can facilitate the collaboration at early stages due to the code quality control, and it can accelerate the peer review process thanks to the reproducible scripts. Despite that the prototype has been drafted following state-of-the-art standards, the protocol and bw2scaffold will be open access so they can be exposed to the scrutiny of LCA practitioners in order to reach a first consensual version in the future. Finally, we argue that the wide adoption of a more mature version of the protocol can help to promote actionable reproducibility in the LCA field.

1.04.P-We004 Improving LCA Data Availability on Yarn Blends in Garments

Heather Logan, Technical Univeristy of Denmark; Valentina Rossi, Technical University of Denmark ; Kamilla Kastrup Hansen, Technical University of Denmark ; Maggie Ziggie Søndergaard, Technical University of Denmark ; Anders Damgaard, Technical University of Denmark.

What makes the textile industry so unique is its embodiment of creativity, self-expression, and individuality; these very characteristics allow the industry to evolve and grow, embracing new trends and forms of self-expression in every season. However, these traits have also led to overproduction and over consumption of textiles, which in turn has resulted in a global crisis in the mismanagement of textile waste. To combat this, the European Union has set requirements for member countries to separately collect and direct these textiles to treatment strategies within the waste hierarchy [1]. Increasing the rate of collection for textiles is essential to developing a successful reuse and recycling market and increasing the quantity of material available to emerging textile recycling routes.

Unfortunately, today, recycled textiles face tradeoffs in balancing the quality and value of recycled materials with the energy and environmental burdens of often chemically and labor-intensive recycling processes [2,3]. Moreover, many of these technologies face barriers in the type of textiles they can recycle, often facing strict criteria for fiber blends [3,4]. Therefore, to accurately assess the potential benefits and opportunities of increased collection and the scaling of emerging recycling technologies, robust data is needed that represents the real composition of textiles in circulation today [4]. Moreover, This data needs to be translatable to LCA datasets, which enable practitioners to model the environmental impacts and potential of textiles and waste treatment alternatives.

This work fills the gap for a representative database on the presence, share, and treatment of yarn blends in the Danish retail market. This is achieved by providing a proof-of-concept yarn database based on a survey of over 5000 garments sold or separately collected within the Danish Market, which identified over 600 unique yarn blends available in the market. This creation of this database aims to aid LCA practitioners in creating more robust assessments of the potential impacts of proposed mitigation and treatment pathways for textiles in Europe. This work fills this gap by providing background-dependent database files that can be immediately used by practitioners in Brightway and EASEtech, as well as an open source and Creative Commons licensed tabular dataset that provides statistics on common yarn blends, their application, and their eligible treatment pathways.

1.05 - Modelling Biogenic Carbon in Life Cycle Assessment

1.05.A.T-01 Biogenic Carbon Accounting: An Open Framework Towards ALIGNED Practices for a Diversity of Bioeconomy Stakeholders

Damien Arbault, INSA Toulouse; Ugo Javourez, INSA Toulouse; Lorie Hamelin, INSA Toulouse.

Addressing climate change has become a top priority in environmental policies, several focusing on replacing fossil-based products with bio-based alternatives. While bio-based materials are initially considered carbon neutral, recent scientific insights highlight that they are not necessarily climate neutral due to the temporal dynamics of CO2 uptake and releases. This nuance often escapes stakeholders' attention, leading to the neglect of biogenic carbon flows in life cycle impact assessments.

Bio-based industries would strongly benefit from harmonized tools and methods for considering biogenic carbon in long-term decision-making and short-term reporting. As part of the EU-funded ALIGNED project, we reviewed the latest related standards and benefited from recurrent workshops with the project's partners to identify gaps between current bioeconomy stakeholders' practices and latest scientific methods for accounting biogenic carbon flows in Life Cycle Assessments (LCAs). Our findings were synthesized into a set of baseline recommendations aimed at achieving consistent, transparent, applicable and comparable climate change impact assessments for bio-based products, across sectors. These recommendations are presented in a tiered approach, to accommodate users with varying levels of expertise and time availability, thus making the latest scientific advancements more accessible and operational for the bioeconomy sectors.

1.05.A.T-02 Comparing Life Cycle Assessment of Biobased and Fossil-based Products – Transition to a Bio- and Circular Economy Demands Fair Comparisons

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Introduction:

The use of bio-based resources is part of the solution for a circular society and are in many LCAs compared with the use of fossil resources for products delivering the same function. However, such comparisons are often influenced by inconsistent handling of the product systems in the LCA set-up and attempts to make fair comparisons of the systems are thus challenged.

Method:

Several approaches have been made to give framework and guidance to the sometimes-challenging prerequisites to make trustworthy and credible LCAs for comparisons using the two different sources for resources.

There are both European and international standard dealing with these challenges, and a JRC published report on LCA for alternative feedstocks for plastics. Yet, the experience in many situations is that LCA comparisons between bio-based and fossil-based use of resources for equivalent functions are failing. The reasons can be already in the basic assumptions for the goal and scope of the LCA, like performance and system boundaries. In the inventory it can be data asymmetry, decision rules for assumptions and finally the impact assessment whether to use 0 as characterization factor for biogenic carbon, or -1/+1.

Mandated in 2012, the European standardization committee for 'Biobased Products', CEN/TC 411, has developed a set of standards for supporting the biobased sector. As a further effort for correct comparisons between bio-based and fossil product systems there is now the development of the European standard, EN 18027: Additional requirements and guidelines for comparing the life cycles of bio-based products with their fossil-based equivalents. It has been out on public consultation and the present work is about handling comments to present a final version.

Result and conclusion:

The new standard focuses on the fact that it is important to perform comparisons correctly following the international LCA standards, ISO 14040, and ISO 14044. The latter document gives clear guidance, listing pre-requisites and requirements for fair and transparent documentation of system boundaries, methodological assumptions, assumptions in models and evaluation and use of data when doing comparisons between systems. Differences between the two systems shall be investigated and analyzed in the Interpretation phase of the LCA to make correct conclusions of a comparison study.

1.05.A.T-03 Dynamic Carbon Footprint For The Full Life Cycle With A Temporal Inventory Database (Dyplca) – Tailoring & Application To Biobased Circular Systems

Thomas Schaubroeck, Luxembourg Institute of Science and Technology; Tomas Navarrete-Gutiérrez, Luxembourg Institute of Science and Technology (LIST); Thomas Gibon, Luxembourg Institute of Science and Technology (LIST); Alya Bolowich, Luxembourg Institute of Science and Technology (LIST); Laurent Chion, Luxembourg Institute of Science and Technology (LIST); Tianran Ding, Luxembourg Institute of Science and Technology (LIST); Ligia Ding, Université de Toulouse; Massimo Pizzol, Aalborg University; Kira Lancz, Aalborg University; Ricardo Méndez, Contactica; Eduardo Entrena-Barbero, Contactica; Josefin Neuwirth, IVL Swedish Environmental Research Institute; Toma Rydberg, IVL Swedish Environmental Research Institute; Ellen Riise, ESSITY; Pernilla Cederstrand, ESSITY; Tamara Coello-Garcia, CESEFOR; Dieuwertje Schrijvers, WeLOOP; Alexandre Charpentier Poncelet, WeLOOP; Enrico Benetto, Luxembourg Institute of Science and Technology (LIST).

Global concerns about climate change and its impacts induced by greenhouse gas emissions and processes make it crucial to understand its evolution over time. This is particularly relevant for biobased systems, which take up CO2 during biomass growth, of which a part remains stored during the life cycle of products (considering possible recycling, reuse etc.), and there is an eventual release at the final end of life (e.g. via incineration). However, in the field of life cycle assessment (LCA) and carbon footprint analysis, a static view is still the dominant approach. Few studies have considered dynamic effects, and if so, only by taking into account time differentiation for the foreground system. Therefore, it is only recently that a fully dynamic LCA has been applied (in this case, dynamic only implies temporal differentiation), in particular through the dynamic process-based LCA (DyPLCA) framework, tool and related temporal database. Yet, there are several aspects needing improvement, A framework has been developed to tackle these gaps, as specified in the next section.
First, the DyPLCA temporal database is a collection of temporal data for all ecoinvent 3.2 processes. Currently, ecoinvent 3.10 is available and contains updated information and new processes. Hence, a straightforward improvement we have done for this framework is the update of the DyPLCA database by LIST in the CALIMERO and LCA4BIO projects.
Second, in the respective DyPLCA database, the temporal flows of forestry systems, especially greenhouse gases, have been considered in a simplistic manner. Emission amounts and their temporal distributions are improved based on the outcomes of a flexible parametric model for a balanced account of forest carbon fluxes in LCA.
A third gap relates to the need to update the climate change impact assessment. INSA Toulouse has developed an advanced tool that already covers different types of effects over time and is compatible with DyPLCA outcomes. This tool and its dataset will be updated.
The final and fourth gap of concern is the limited tailored loop modelling for wood cascading systems in ecoinvent and DyPLCA. This is ameliorated by systematically incorporation useage processes with their durations, the possiblity to adapt number of loops and the handling of recycling/reuse.
An application to two cases of the CALIMERO project is envisioned: (1) one on laminated strand lumber (LSL) & (2) the Swedish pulp and paper sector.

1.05.A.T-04 Requirements and Guidelines for Comparative LCA of Bio-based Products with their Fossil-based Equivalents

Iris Vural Gursel, Wageningen Food & Biobased Research.

Background and Purpose: Problems often arise when comparative LCA's need to be performed between biobased and fossil based products and different methodological choices can be made. The results of the LCA study may strongly depend on these choices. This calls for additional requirements and guidelines to make sound comparisons.

Methods: Initially an inventory of technical topics was made to be addressed which are critical in carrying out comparative LCAs between biobased and fossil based products on equal footing. The additional requirements and guidelines were developed based on a sound review of existing approaches not only in relevant EN and ISO standards but also in scientific literature in collaboration with a team of European experts as part of the CEN Technical committee 411 working group.

Results: One of the key topics is accounting for removals and emissions related to biogenic carbon and its temporary storage. Currently, there is no full consensus on an internationally recommended approach in dealing with this topic. Information on the different approaches recommended by relevant standards and guidelines were reviewed and the following requirements were defined. The inventory of biogenic carbon flows shall include both the removals and the emissions with dedicated elementary flows. For cradle to gate studies, biogenic carbon content in the products shall be reported separately to allow calculation of biogenic carbon emissions in end-of-life. the biogenic carbon shall be quantified applying the -1/+1 approach. For the assessment of effect due to temporary biogenic carbon storage dynamic approach is recommended. The portion of the stored carbon not emitted to the atmosphere within the chosen time period may be treated as permanently stored.

Other key topics addressed include Handling of emerging technologies; Data asymmetry; Modelling end-of-life scenarios; Inclusing of biodiversity and indirect impacts. The requirements and guidelines concerning these are provided in the European standard prEN 18027.

Conclusions: This study identifies and addresses specific challenges in carrying out comparative LCA between biobased products and their fossil-based counterparts. Since these comparative LCAs are used for building policies for biobased products in Europe and by many stakeholders for decision making about the choice of materials, it is evident that such a guidance is sought after for making scientifically sound and fair comparisons.

1.05.A.T-05 9,000+ Deforestation Carbon Footprints for Agricultural Commodities: A Global Life-Cycle Inventory Database

Martin Persson, Chalmers University of Technology; Chandrakant Singh, Chalmers University of Technology.

Background: Land-use changes—primarily the conversion of natural forests and other ecosystems to cropland and pastures—accounts for 20-25% to total food system greenhouse gas emissions. Despite this, most large-scale LCA databases still rely on old data sources and crude models to estimate life cycle inventory (LCI) data on land-use change (or 'land transformation') for agricultural products, disregarding recent advancements in remote-sensing data on forest loss, land use and commodities extent, and carbon stocks, as well as key land-use change dynamics such as land use replacement and degradation.

Methods: The Deforestation Driver & Carbon Emission (DeDuCE) model aims to provide improved estimates of deforestation—and associated carbon emissions—linked to cropland, pasture, and forest plantation expansion globally by overlaying satellite data on forest loss with maps of specific crops and land uses, attributing deforestation to commodities with high spatio-temporal accuracy. When direct spatial attribution is not possible, the model employs agricultural and forestry statistics in a two-step process to allocate deforestation to specific land uses and commodities. Carbon losses from deforestation are estimated using forest carbon stock maps, while peatland drainage emissions are calculated by overlaying deforestation data with global peatland extent maps.

Results: The DeDuCE model provides a harmonized LCI database, detailing over 9,100 unique deforestation carbon footprints, for 184 commodities and 176 countries in the year 2022. The database also includes sub-national LCI data for Brazil and Indonesia, which account for approximately 40% of annual tropical forest loss. Incorporating a model of international agricultural commodity trade, we enhance the accuracy of lowest-tier land-use change LCIs by replacing global production-weighted averages with consumption-weighted averages based on sourcing countries, providing a more precise estimation of carbon footprints.

Conclusions: Our study improves existing LCI databases by refining methods for estimating the deforestation footprint of agricultural commodities. This work supports private sector initiatives (such as corporate reporting under the SBTi FLAG initiative) and public policy (such as the EU Deforestation Regulation) in addressing agricultural commodity-driven deforestation and its climate impacts, representing a crucial step towards more sustainable food systems and effective climate action.

1.05.B.T-06 Quantifying the Climate Impacts of Wood-Based Construction in LCA – Importance of Considering Biogenic Carbon and Forest Management Dynamics

Ambrose Dodoo, Linnaeus University; Bishnu Chandra Poudel, Linnaeus University; Johan Bergh, Linnaeus University.

Wood-based construction products and buildings present unique challenges in LCA due to the complexity of their life cycles. To conduct a comprehensive LCA of wood-based products and thereby produce results that contribute to robust climate change decisions and policies, it is crucial to consider all stages, including forestry dynamics and associated biogenic carbon flows. A significant share of the GHG fluxes in the wood-based system is biogenic, arising from the uptake of carbon in growing tress, forestry operations, product transportations, the storage of carbon during the service life of wood-based products, the use of wood residuals for processing energy in wood industries, and the release of stored carbon during harvest and end-of-life management of wood. However, LCA of wood-based construction currently have limitations in how biogenic carbon flows are accounted. Typically, in such LCAs, biogenic carbon linked to wood construction materials is accounted assuming neutrality and the dynamic behaviors of biogenic carbon and the storage of the biogenic carbon are neglected.

This study explores methods for biogenic carbon accounting in building LCA and their implications when quantifying the climate impacts of wood-based construction. The climate impact of a case-study massive timber building system is modeled from a life cycle perspective, considering both fossil and biogenic carbon flows associated with forest systems, energy supply, material production, use, and end-of-life management. The study analyzed the annual GHG flows over the life cycle of a wood-based building system and associated instantaneous and cumulative radiative forcings, providing a robust understanding of the climate impacts of wood-based systems. The analysis shows considerably different results when biogenic carbon is accounted for versus when it is not in the LCA of the studied massive timber building systems. This highlights the importance of robust accounting of forest management dynamics, including biogenic carbon flows, in the LCA of wood-based building systems. Overall, this study's findings offer holistic insights into the climate impacts of wood-based building systems, facilitating informed decision-making in sustainable construction practices, and effective climate change mitigation strategies.

1.05.B.T-07 Life Cycle Assessment of Wood-Based Textile Products: Using a Flexible Parametric Model for Carbon Accounting

Adisa Ramadhan Wiloso, University of Helsinki; Hanna L. Tuomisto, University of Helsinki; Elias Hurmekoski, University of Helsinki.

This study aims to evaluate the environmental impact of dress products made from wood fibers using retrospective life cycle assessment (LCA). Our cradle-to-grave LCA applied attributional approaches that includes carbon balance analysis to understand the complete story of biogenic carbon removal and emissions in the life cycle of the product under investigation. The product system being developed represents average technology in the European region within 2010 to the present time. The life cycle inventory (LCI) for dress products was compiled from several sources, including scientific literature, national reports, and databases, to model processes in the downstream and upstream parts of the product life cycle. Focusing on developing LCI for forestry activities, we employed a flexible parametric model proposed in the literature involving the so-called CARBINE model to facilitate carbon sequestration accounting. We defined the functional unit as one meter square of dress products made from wood fibers produced in the European region. Six midpoint impact categories, consisting of global warming, acidification, eutrophication, cumulative energy demand, water use, and land use, were considered in our assessment using openLCA software. As for the results, we expect that the environmental impact of this particular textile product will vary considerably depending on the downstream modeling scenario, mainly due to variations in recycling schemes (and rates) and lifetime assumptions. To this end, our analysis focuses on exploring different scenarios in modeling the downstream stages of the product life cycle as part of the sensitivity analysis. We believe that the inclusion of a carbon balance approach in our study is critical since the product's lifetime strongly determines how long biogenic carbon is retained in the product, and such an approach can reveal otherwise hidden information regarding the temporal aspects of the system under study. Our study can serve as a baseline that provides key environmental profiles for a viscose-dress product, taking the whole life cycle perspective while also considering biogenic carbon balance accounting.

1.05.B.T-08 Unraveling the Climate Neutrality of Wood Derivatives and Biopolymers

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Bio-based materials are widely perceived as climate-neutral. To validate this perception, we conduct a lifecycle scenario analysis for biopolymers, namely lignin and cellulose nanofibrils, derived from wood. The resulting carbon footprints vary between climate-positive and climate-negative values: -2.06 to 14.95 kg CO2 eq./kg for lignin and -1.57 to 12.20 kg CO2 eq./kg for cellulose nanofibrils. In contrast, the carbon footprints for conventional fossil-based polymers have lower variability but do not exhibit climate positivity. This variability in carbon footprints is a result of: i) the specificities of the material lifecycle i.e., the extraction processes, duration of the use phase, and End-of-Life management; ii) accounting of biogenic carbon; iii) biodegradability. In order to leverage the potential climate benefits of bio-based materials, efficient production pathways have to be established, their duration of use should be maximized, and EoL mismanagement leading to unintended greenhouse gas emissions should be avoided.

1.05.B.T-09 Life Cycle Assessment of Bioenergy with Carbon Capture and Storage: a Sweden-Norway Case Study

Kåre Gustafsson, KTH - Royal Institute of Technology; Fabian Levihn, KTH - Royal Institute of Technology; Cecilia Sundberg, Swedish University of Agricultural Sciences (SLU); Anna Björklund, KTH - Royal Institute of Technology.

The Intergovernmental Panel on Climate Change (IPCC) has analysed a multitude of scenarios for keeping global warming at safe levels. These scenarios rely on drastic emission reductions of greenhouse gases (GHGs) and often on massive deployment of atmospheric carbon dioxide removal technologies. Among those, the most featured technology is bioenergy with carbon capture and storage (BECCS). Despite this, few BECCS projects have been realized. One challenge is the trade-off between different environmental impacts. Previous publications have shown that while BECCS projects generally contribute to climate change mitigation, other impact categories can be negatively affected. These shift-of-burdens are context dependent, thus requiring project-specific studies. This study utilizes life cycle assessment to examine the environmental implications of a BECCS project that is in the planning stage. The intention of the project is to capture CO2 at an existing biomass-fired, combined heat and power plant in Stockholm, Sweden. The captured CO2 is to be transported by ship for storage under the seabed outside Norway. To understand how methodological choices affect the results, this study applies two analytical perspectives. The first is attributional and provides insights to the projects absolute share of global environmental burdens. The second is consequential and investigates the net marginal change in environmental impacts. From a climate point of view, this study shows that the BECCS project will 1) generate below zero GHG emissions in absolute terms and 2) provide a net reduction of GHG emissions. This is true even when varying the assumption on the electric power production background system, which is the parameter with the greatest influence on the results. As for other impact categories, both acidification and eutrophication increase slightly due to the project. The application of both ALCA and CLCA yielded interesting results. Especially noteworthy is that the project appeared more benign when using ALCA. This shows that methodological choices matter and that by applying two methods, more robust results can be provided. In summary, the studied BECCS facility has the potential to provide substantial reduction of GHG emissions, while appearing to not cause major shift-of-burdens. Thus, it can be concluded that deployment of BECCS in the right setting can contribute to the fulfilment of scenarios for keeping global warming within safe limits.

1.05.B.T-10 Dynamic Life Cycle Assessment of Climate Change Impacts in Biochar Systems

Magnus Karlsson, Roskilde University (RUC); Andreas Kamp, Roskilde University (RUC); Tobias Pape Thomsen, Roskilde University (RUC).

Background and Purpose
Acceleration of novel carbon dioxide removal (CDR) is necessary in all IPCC scenarios that meet the Paris agreement temperature goal. Biochar is a highly competitive CDR technology with a high scaling potential. In Danish policy, an ambitious target has been set of 2 Mt CO2 reduction in the agricultural sector through biochar application to soils. This calls for accurate assessment of climate change impacts of biochar systems.
The mechanism of emissions reductions through conversion of biomass into biochar is the postponing of biogenic carbon emissions through decreased soil carbon decay rate. Dynamic modelling of soil emissions is therefore necessary to accurately assess climate change impacts in biochar systems and allows for assessment of impact timing relevant for policy in the age of urgent climate action need.

Methods
In this study climate change impacts of straw and biogas digestate biochar systems are assessed through consequential life cycle assessment with dynamic temporal life cycle inventory (LCI) of soil carbon stocks for biochar and reference biomass.
Impacts of biomass management systems are modelled stochastically with all key model parameters defined as probability distributions based on literature review of data and primary model development enabling assessment of the range of effects achievable in biochar systems.
A probabilistic model of methane emissions based on storage period data is developed for assessment of emissions reductions achievable by stabilization of biologically active biogas digestate through pyrolysis.

Results
Results are expressed through dynamic global warming potential (GWP) and global temperature potential (GTP) indicators and visualized as time series for assessment and comparison of timing of climate change impacts.
Results based on static and dynamic LCI data are compared to assess the increased accuracy in impact assessment gained through dynamic modelling.

Conclusions
Dynamic modelling provides more accurate assessment of climate change impacts in biochar systems and enables interpretation of timing of effects relevant for climate policy.
Climate change impacts in biochar systems are highly dependent on system configuration. Flow of carbon through the system toward biochar and reductions in methane emissions in biogas digestate systems are most influential on results.

1.05.P - Modelling Biogenic Carbon in Life Cycle Assessment

1.05.P-We006 Critical Review: State of the Art of Dynamic Life Cycle Assessments for Bio-Based Products

Marle de Jong, Utrecht University; B.C. Bellostas, B.C. Bellostas, Utrecht University; L. Shen, Utrecht University.

Background and purpose:

Most life cycle assessments (LCAs) are static, lacking spatial and temporal resolution for climate, water, and biodiversity impacts. These parameters are highly important in assessing environmental impacts of bio-based products. Also, understanding the influence of biogenic carbon accounting is crucial but lacking. A dynamic LCA (dLCA) is a LCA framework that can analyse these temporal and spatial explicit issues. We aim to provide a critical systematic literature review of recent dLCAs, with the focus on bio-based systems and products.

Methods:
We conducted a systematic literature review on Web of Science, searching keywords related to dLCA, bio-based products, and biomass, without limitation of publication time and only including peer-reviewed articles. Out of 38 results, 28 articles (with 19 case studies) were reviewed up till now, analysing sector/product, dLCA definition, dynamic elements (inventory, characterization - spatial/temporal), and biogenic storage accounting.

Preliminary results:
Interest in dLCA has grown, notably in the last five years, with main applications of dLCAs in building sector (10 out of 19 case studies) and in bioenergy (5), and in products with a longer life time as wooden (frames for) buildings (4 out of 19 case studies), bio-based concrete (3), and insulation (3). A lack of an uniform dLCA definition and varying application reasons were evident, creating ambiguity in the results of published dLCAs. The term dLCA usually connotes temporal changes and less spatial parameters, indicating a limited application of dLCA. In fact, there is only one paper known which combines spatial and temporal elements.

This ambiguity is also seen in the way and the degree to which dynamism is applied in LCAs. Including dynamic characterization is common (17 out of 19 case studies), while including dynamic inventories is less frequent (7). The dynamic process inventory ranged from incorporating two to four dynamic parameters. Only six studies include both dynamic characterization and inventories.

The research on the biogenic carbon accounting is not finished yet.

Conclusions:
This research highlights key knowledge gaps in current dLCAs of bio-based products, guiding future research towards a standardized methodology for analysing bio-based systems.

1.05.P-We007 The Environmental Potential of Hydrogen and Acid from Bio-alcohols: Reality or Biogenic Carbon Accounting Artifact?

Inga-Marie Lahrsen, Energy & Process Systems Engineering, ETH Zurich; Eleonora Bargiacchi, ETH Zurich; Johannes Schilling, ETH Zurich; André Bardow, ETH Zurich.

Background and Purpose
Biomass is crucial in replacing fossil feedstocks in the chemical industry to reduce climate change impacts. Dehydrogenating bio-alcohols is particularly interesting by co-producing a high-valuable chemical, e.g., an acid, along with hydrogen. However, the environmental potential of those biomass dehydrogenation processes still needs to be determined compared to state-of-the-art production processes.

Method
In this work, we investigate the environmental potential of the dehydrogenation of various biomass options. For this purpose, we model biomass dehydrogenation for several biomass options, assuming ideal performance to calculate the minimal achievable environmental impacts with life cycle assessment. These minimal environmental impacts are compared to state-of-the-art benchmarks to quantify the environmental potential.

Results
Our case study considers dehydrogenation reactions generating hydrogen alongside four potential acids. Our findings highlight the acids with the largest ecological advantages over traditional fossil and green benchmarks across various environmental impact categories. Conversely, our findings identify acids that do not exhibit any notable environmental benefits compared to existing benchmark technologies across multiple impact categories in our case study.

While these results are encouraging, we observe methodological challenges from biogenic carbon emissions accounting: the environmental potential increases when switching from the 0/0 to the -1/1 approach for biogenic carbon emissions accounting related to biomass feedstock carbon uptake in a cradle-to-gate assessment. Moreover, we identify challenges in combining biogenic carbon balancing with the -1/1 approach with a cut-off approach and waste incineration at the end of life in a cradle-to-grave assessment; in this case, actually, biogenic carbon uptake is allocated to bio-based products while a large amount of biomass waste is burden-free.

Conclusion
In summary, our analysis affirms the environmental potential of biomass feedstock use in multi-product systems. The applied method provides a practical and effective means to eliminate immature technologies that fall short of current benchmarks in sustainability. Simultaneously, it identifies immature technologies with potential for further investigation and development. Furthermore, our results show we can gain meaningful insights into biogenic carbon accounting in bio-chemical production.

1.05.P-We008 Impacts of Biogenic Carbon: New Forestry Based Emission Factors

Stefan Füchsl, Technical University of Munich (TUM); Hubert Röder, Technical University of Munich (TUM).

Biogenic carbon and its stocks and flows play a significant role for earth’s climate and increasingly for climate action. There is a rising interest in biogenic raw materials as alternatives for fossil resources as well as a clear recognition of the role of forests in the fight against climate change. However, in Life Cycle Assessment (LCA) biogenic carbon flows have historically been largely ignored as climate neutral with only few methods incorporating biogenic carbon emissions for impact assessment. Thus, the existing methods are often difficult to implement, ill fitting with other aspects of LCA or only rough in assessing the impact of biogenic carbon flows. New and more accurate indicators for biogenic carbon are especially needed for forestry and products from slow growing biomass.
This study calculates biogenic emission factors for wood from forests representing typical Central European types of forests, ages, and harvest intensities. For this goal, five representative forest stands were constructed based on data from the 2012 federal forest inventory of Germany and five age groups for each forest were considered. In each forest of each age class harvest events were simulated and compared to a baseline scenario without these harvest

events. The resulting biomass growth was expanded to cover the full above and below ground biomass, while deadwood and soil carbon were simulated with the YASSO20 tool. The resulting dynamic inventories for each harvest event compared to the non-harvest scenario served as the basis for the calculation of biogenic emission factors using a dynamic LCA approach.
The biogenic carbon emission factors calculated in this study thus consider the full range of biomass growth in forests of different species compositions, age, and harvest intensity, while also considering the lost growth by comparing to a non-harvest scenario. These novel emission factors advance the consideration of biogenic carbon by allowing practitioners to use ready made factors for a wide range of wood based products or to employ the presented method to calculated own emission factors in a more adaptable, easy to use way. Furthermore, this study uncovers the impact of different aspects of slow growing biomass, such as age, species or harvest intensity on impacts. This enables a much more precise long term assessment of forest management activities to mitigate climate change.

1.05.P-We009 Potential Carbon Sequestration of Biochar Using Willow Biomass in Sweden
Pierre Van Rysselberge, Swedish University of Agricultural Sciences; Cecilia Sundberg , Swedish University of Agricultural Sciences; Niclas Ericsson, Swedish University of Agricultural Sciences; Johan Karlsson, Swedish University of Agricultural Sciences; Per-Anders Hansson , Swedish University of Agricultural Sciences.

The escalating global need to mitigate greenhouse gas (GHG) emissions calls for innovative solutions in agriculture, a sector intrinsically linked with unavoidable emissions such as nitrous oxides and methane. This study aims to identify and enhance agricultural systems incorporating effective carbon sinks, striving towards net zero GHG emissions. The objective is to evaluate the potential of specific carbon sinks of biochar, using biomass from willow production, to absorb CO2 from the atmosphere. This study models the potential for all agricultural land in Sweden. Using a lifecycle assessment (LCA) approach, our research delineates the time-dependent climate effects of this strategy, clearly distinguishing between carbon sequestration and avoided emissions—the latter representing reductions achieved through the substitution of fossil inputs. Additionally, the data for biochar efficacy comes from field studies, ensuring realistic and applicable results. The study further explores the geographical variations in the efficacy of these carbon sinks and assesses their scalability on a national level. One conclusion is that the carbon sink created by the Salix-biochar system is substantial and may play a central role in the creation of a net-zero agricultural production system. Another conclusion is that the avoided emissions are strongly dependent on the assumed energy substitution, while the carbon sink results are most dependent on the stability of the biochar.

1.05.P-We010 System Analysis and Life Cycle Assessment of Sustainable Transformation Strategies for the Chemical Industry
Patrick Veiltl, Technical University of Munich (TUM); Matthias Gaderer, Technical University of Munich (TUM).

The European chemical industry faces a substantial challenge while striving to reach decarbonization goals. The industry needs to undergo a sustainable transformation with regards to energy and feedstock utilization. Different technological solutions are sketched out by the scientific community and industry leaders on a daily basis, ranging from direct electrification of process heat supply or new synthesis routes utilizing bio-based feedstocks. Renewable electricity, energy carriers like green hydrogen, as well as educts like green methanol will all gain importance in the foreseeable future to substitute fossil fuels as energy and carbon sources. However, these technological pathways all differ in their efficacy to reduce overall global warming potential (GWP) and might even have conflicting prerequisites.

An overarching approach is needed to evaluate transformation pathways on a system level, while still maintaining a detailed focus on key processes (e.g., ammonia production, petrochemistry, fuel synthesis) and the necessities of individual production facilities.

To this end, a thorough literature review has been conducted to gather data on available technologies and their potential applicability in both small and large-scale processes. This data is then evaluated using a system-level approach coupled with Life Cycle Assessment (LCA) to categorize its potential to reduce GWP and further environmental impact.

Achieving a carbon-neutral chemical industry requires extensive measures. The supply of primary feedstocks and base chemicals like methanol, ethylene, and hydrogen will depend on international supply chains and a robust transportation infrastructure, connecting regions with abundant renewable electricity to high-demand chemical production clusters. Additionally, expanding the electricity grid to connect these regions is crucial. The utilization of Carbon Capture and Utilization (CCU) technologies will also play a pivotal role in ensuring a sustainable carbon supply within the circular economy, as carbon remains a fundamental building block of the chemical industry.

This work aims to highlight the critical pathways and systemic changes required for the sustainable transformation of the European chemical industry, emphasizing the need for integrated technological solutions and robust infrastructure development.

1.05.P-We012 Application of LCA to document Carbon Dioxide Removals (CDR) from Pyrolysis and Incineration of Waste
Hanne Lerche Raadal, Norwegian Institute for Sustainability Research (NORSUS); Ingunn Saur Modahl, Norwegian Institute for Sustainability Research (NORSUS).

Background and Purpose:
Pyrolysis is a waste treatment method which, in the same way as incineration with energy recovery, can be combined with Carbon Capture and Storage (CCS). Based on the amount of biogenic carbon in the waste, both pyrolysis and incineration with energy recovery have the possibility of removing carbon dioxide from the atmosphere. This study aims to demonstrate how LCA can be used to model the different treatment methods to comparably document the possible Carbon Dioxide Removal (CDR) potential of the treatment options. This is relevant for upcoming certification schemes for CDR, such as the EU carbon removal certification framework.

Methods:
A scenario-based screening life cycle assessment (LCA) approach is applied through a zero-burden approach for waste LCA modeling in SimaPro®. The functional unit is treatment of one tonne of waste with a certain share of biogenic and fossil carbon content. Both uptake and release of biogenic CO2 is included in order to visualize the biogenic share of the waste. Uptake of biogenic CO2 is connected to the biogenic carbon content, which is a physical characteristic of the waste. Emissions of biogenic CO2 are assumed to cause the same climate change as fossil CO2. In total, uptake and emissions of biogenic CO2 will cancel each other out, if not biogenic CO2 is stored permanently. When adding negative and positive emissions throughout the value chain, potential net negative emissions are documented as CDR. The pyrolysis and incineration systems are analysed with and without CCS connected to the

emission point source being the flue gas from either combusting the pyrolysis gas or from incinerating the waste.

Results:
The results show that pyrolysis might result in net negative emissions even without CCS since treatment of the char itself leads to carbon storage. If CCS is added to the combustion process of the pyrolysis gas, the net negative emissions will increase radically. For waste incineration with energy recovery, net negative emissions for the system can only occur in the combination with CCS.

Conclusions:
The study shows how potential Carbon Dioxide Removals (CDRs) from different waste treatment methods can be modelled in LCA by including the uptake of biogenic CO2 as biogenic content in the waste under study.

1.06 - Approaches and Case Studies in Scaling Up LCA

1.06.A.T-01 AstraZeneca's Approach to the EcoDesign and Environmental Impact Quantification of Medicines
Chloe Smithers, AstraZeneca; Paulina Ignasiak, AstraZeneca.

Background and Purpose: AstraZeneca have an established LCA (Life Cycle Assessment) program that has been running for over 10 years which previously focused on our established products. The introduction of our ambitious carbon targets (carbon negative by 2030, net zero by 2045) has created the need for us to develop tools and capabilities to give scientists what they need to be able to make robust sustainable decisions during the development process of new medicines. The success of any platform is underpinned by the quality of data we use to model our processes.

Method: An internal suite of tools has been successfully developed which bring sustainability to the hands of scientists. These tools make resources and data accessible, which facilitates the modelling of complex manufacturing processes. A framework has also been created to assign carbon targets to all development products to drive sustainability performance to meet our targets. The suite of tools in combination with the carbon target framework makes it possible for scientists to understand the improvements required to achieve our sustainability goals.

Results: The tools we are developing include:
-AZ Materials Database: Internal process data library that covers the many data gaps that are present in pharmaceutical manufacturing processes. The database provides easily accessible LCA impact data, without the need to use LCA software or be an expert in LCA, of materials used within our processes, and allows for quick comparison of materials.
-LCA-Lite: Intuitive online tool that allows scientists to conduct complex LCA modelling of development processes from cradle to gate. The tool also provides scientists the ability to explore the impacts of greener manufacturing processes and can facilitate scientists in making the right decisions throughout development based on environmental performance.
-LCA AI Data Tool: through combining the innovative functionality of AI with the visual capabilities provided by a graphical database, we have developed a tool that allows interrogation of a data matrix including LCA, volume and forecasting data through using natural language to ask relevant questions commonly asked to LCA experts.

Conclusions: The toolkit has been designed to meet sustainability needs within the business where there are currently capability gaps. By simplifying the data and enabling it's use in decisions, it will be possible to effectively target lower environmental impact medicines.

1.06.A.T-02 Semi-Automatic Tool for Large-scale Production of Environmental Product Declarations
Maresa Bussa, ESU-services GmbH; Niels Jungbluth, ESU-services GmbH.

The demand from our customers for Environmental Product Declarations (EPD) is increasing. Companies are looking for options to calculate environmental impacts for a wide range of their product portfolio in a short time frame. This work presents a semi-automatic approach to model and calculate EPD without reducing the level of detail of the analysis options.
The presented solution uses the programmable two-way interface of SimaPro 9.6 to model the products based on their bill of material information and calculate the results according to the guidelines of PEP Ecopassport for electrical and electronic products. The bill of materials includes information on materials, processing technologies as well as suppliers and is linked to a matching list which ties the information to available background datasets. Additional information not included in the bill of materials, e.g. energy consumption of the manufacturing stage can be entered in a simple interface. The model includes uncertainty information based on the pedigree approach and the use can chose from different scenarios for transport, manufacturing and use phase locations as well as disposal pathways. The tool calculates the mandatory and optional environmental indicators for each life cycle phase and the inventory indicators required for environmental product declarations. To derive potential measures for product improvement, a hotspot analysis of the manufacturing stage is provided, which assesses the contribution of raw materials production, raw material processing, transportation and in-house energy consumption. The contribution to the environmental impacts of each material is set into relation to its contribution to the weight of the final product to identify environmentally critical materials. Additionally, life cycle inventory tables for the report are provided. The user can access the model directly in SimaPro for a more detailed analysis of the upstream chain or a Monte-Carlo Simulation.
As only few manual data entries are required and the modelling and calculation work is automized, the tool allows to finish reports for environmental product declarations within hours while the full transparency of the model remain.

1.06.A.T-03 Enhancing Efficiency in Environmental Product Declarations Generation through Automation and Database(s) Integration
Aleksandar Lozanovski, Siemens AG; Manfred Russ, Siemens AG; Alexander Bayer, Siemens AG.

Climate Change and other environmental hazards are one of the greatest risks of our time. To tackle this, a common method is creating transparency by Environmental Product Declaration (EPDs), for example, followed by optimization. In a large company like Siemens AG, there is a vast product portfolio with a great variety of different kinds of products. This makes it time-consuming and resource intensive to calculate EPDs manually.

On the other hand, there is a significant amount of data existing within the company but a) distributed in many different databases which are not connected and b) data is partly unstructured and ambiguous. So, one option is to link different databases and tools with all the efforts of matching different data structures and hierarchies. But connecting the dots of databases and tools accompanied by data cleansing and structuring creates opportunities for automatization that can lead to efficiency gains. Another possibility includes the archiving of calculated parts and (sub-) assemblies in the EPD calculation tool Green Digital Twin to be available for future calculations from the same or another person.

To overcome these challenges, Siemens AG has created the Green Digital Twin, which is an internal tool for calculating Environmental Product Declarations in an efficient manner. Efficiency is gained by connecting a database containing technical information on electronic parts like their type, dimensions, and mass with the LCA database results to automatically calculate the environmental impact of electronic parts just by entering a part ID.

The part ID is also used for an autofill function. If someone enters technical information and matches the part ID to an LCA dataset, the next time the same part ID is used in a calculation, the information entered last time can be reused again for saving time and efforts.

Creating the Environmental Product Declaration is also time consuming. Previously, results from the used LCA database had to be exported to Excel to create graphs and then copied them into a Word document. In this Word document, additional fields like functional unit, product description, and more had to be entered manually. This is automated by having fields to enter information inside the Green Digital Twin EPD Tool. This entered information, along with automatically calculated graphs, result in an PDF document created by the tool without the need of using Excel or Word.

Implementing these automation and integration techniques in the EPD process has proved feasible in daily work. Significant time savings have been achieved, on average 5 days of work are saved for creating an EPD.

1.06.A.T-04 Integrating Systematic Product Group Information with Singular Bills-of-Material for Efficient Life Cycle Assessment Scale-up

Thomas Betten, Fraunhofer Institute for Building Physics IBP; Jonas Keller, University of Stuttgart; Bianka Engelmann, SICK AG; Daniel Wehner, Fraunhofer Institute for Building Physics IBP.

Driven by an increasing number of Life Cycle Assessment (LCA)-related regulations coupled with companies' own climate strategies and stakeholder inquiries, the demand for product-related sustainability information is growing. This demand cannot be met by merely expanding LCA capacities; instead, efficiency in LCA processes must be improved. Many companies, primarily manage data focusing on technical and monetary parameters, often lacking critical data for conventional LCA, which relies on detailed bill-of-materials. This gap makes updating data time-consuming, particularly for extensive product ranges, presenting a major challenge due to the uncertainty and dynamic nature of normative requirements and varied databases for different products. However, product departments and domain experts possess valuable semi-formalized knowledge about product variants which can aid in assessing product groups. This paper proposes the subtraction approach that integrates information across product variants with conventional bill-of-materials data, offering a method that can be rapidly implemented for initial assessments and later refined to meet complex requirements.

Using the Sustainability Data Science Life Cycle concept, we identified the main requirements and simplification areas for the subtraction approach, focusing on integrating and efficiently utilizing existing data sources, ensuring short-term operational readiness, and evolving with increasing data complexity and regulatory changes. Primary data sources for a reference product group were identified and evaluated for their readiness for LCA calculations, with additional high-level product group variant information used to reduce complexity.

The subtraction approach integrates product group level data with individual product data for LCA calculations, improving data usage efficiency and reducing complexity. This method starts with identifying relevant product-level data and key product group parameters. The coverage rate of specific components is quantified before detailed LCA modelling is conducted for a reference product, allowing for the calculation of sustainability information across the product group using both specific and generic modelling approaches. The subtraction approach enables companies to begin generating product-related sustainability information without compromising flexibility for future requirements. Its main advantages include efficient data use and complexity reduction.

1.06.A.T-05 Learnings from 15 Years of Using Life Cycle Assessment to Assess Absorbent Hygiene Product Portfolios Over Time

Sandra Franz, Essity Hygiene and Health AB; Sandra Franz, Essity Hygiene and Health AB; Madeleine Pehrson, Essity Hygiene and Health AB.

In addition to life cycle assessments (LCAs) on individual products, LCA can be used for performance tracking of entire product portfolios. Such assessments come with several methodological challenges, both when it comes to methodological choices to make, and the efforts required to assess large product assortments. Examples in literature is still relatively few and guidance in standards is limited.

The company Essity Hygiene and Health AB has performed LCAs on different parts of its assortment of absorbent hygiene products (feminine products, baby diapers and adult incontinence products) regularly since 2009. The portfolio-LCAs has compared the current assortment to the historical assortment in the baseline year 2008. This conference contribution presents methodological learnings from 15 years of performing portfolio LCAs of absorbent hygiene products.

Absorbent hygiene products are sold in a wide variety of sizes and absorption levels. This means that to assess the full product portfolio requires hundreds of articles to be modelled, starting from bill-of-materials (BOMs). This conference contribution presents, e.g., an approach to create BOMs for average weighted products (weighted based on sales mix), in a structured way, based on information on produced volumes in the company's manufacturing units and information on volumes of materials purchased from different suppliers. It also presents an approach for modelling the waste handling from such portfolios and discusses challenges in upstream supplier inventories when doing historical comparisons.

Historical portfolio-LCAs enables the company to build knowledge regarding the environmental impacts connected to their product portfolio, how it develops over time, and enable identification of hotspots. Results are influenced, e.g., by product development efforts, supplier material development, or changes in the surrounding technical system (such as the waste handling in the different region where the products are used), but also on changes in the sales mix or the launch of new products.

This case study shows the usefulness of portfolio- LCAs for assessing absorbent hygiene product portfolios, highlights several methodological challenges in such assessments, and displays how these challenges can be addressed.

1.06.B.T-06 Considering Stakeholder Perspectives for Increased Usability of Life Cycle Assessment Software Tools by User Story Mapping

Johanna Holsten, Technische Universität Braunschweig; Steffen Blömeke, Technische Universität Braunschweig; Christoph Herrmann, Technische Universität Braunschweig.

In recent years, the application of life cycle assessment (LCA) has surged across various industries, driven by increasing environmental awareness and regulatory requirements. However, this rapid adoption has outpaced the expertise available in many companies, industries, and regions to effectively apply the complex LCA methodology. Challenges such as consistent modeling and data quality issues persist, prompting the development of specialized LCA tools. Despite these advancements, the transition of these tools to industrial applications remains limited, often due to their complexity and the specialized knowledge required, leading to risks of improper use and flawed decision-making.

Therefore, this presentation aims to address these challenges by examining the needs and experiences of different LCA user groups. Through literature analysis and user story mapping, this research identifies stakeholders involved in LCA processes and maps their activities to enhance tool usability and user experience. The user story mapping method provides a comprehensive perspective on stakeholders' roles and requirements, ensuring future LCA tools are better aligned with user capabilities and needs.

The analysis reveals that both academic and industrial LCAs involve diverse stakeholders across various divisions, such as product development, procurement, and production planning. These stakeholders influence the life cycle phases and environmental impact of products and serve as crucial data providers. Additionally, it is essential for one individual user or group to oversee the entire LCA implementation. Given the varying levels of expertise among these users - ranging from researchers and sustainability specialists to product developers - LCA tools must be tailored to accommodate different levels of functionality based on the user's experience and the LCA's objectives. User story maps are used to visualize the individually needed functionalities of LCA tools, organized according to the four phases of an LCA. Each phase encompasses specific user tasks, which can differ in complexity and detail.

The user story map developed in this study together with the personas derived is intended to enhance the usability and applicability of future LCA tools, ensuring they are better suited to the varied needs of their users. This approach aims to facilitate more accurate and efficient LCAs, promoting their broader adoption and effective implementation across different sectors.

1.06.B.T-07 Whole Life Carbon Assessment of Buildings at Urban Scale

Tove Malmqvist, KTH Royal Institute of Technology; Oleksii Pasichnyi, KTH Royal Institute of Technology; Sacha Thibault, KTH Royal Institute of Technology.

As we near 2030, an increasing number of municipalities are setting ambitious targets, ranging from halving their emissions to aiming for net-zero status. Several objectives are set from a consumption perspective, increasing interest in accounting consumption emissions and strategic planning ahead to reduce them. In addition to tools that attempt to manage all such emissions in a geographical unit, new approaches are emerging to support physical planning. Construction and operation of both buildings and infrastructure are major contributors to cities' footprint. Modelling these GHG emissions over time is crucial for understanding the trade-offs between emissions 'invested' in interventions and energy efficiency gains in the long run. However, to this day, it remains challenging to model future emissions with a precision that would suffice for a tool to become relevant for decision-makers.

The aim of this study is to develop a framework for the whole life carbon (WLC) assessment of existing and future buildings on an urban scale. This is done through accounting the GHG emissions associated with different building development pathways including a baseline scenario, as well as the impact of interventions of different nature, including energy renovations, demolition and construction of buildings. An interactive prototype tool is then proposed to set up, visualise and compare various building stock development scenarios. Finally, the framework is illustrated for the Kista/Järva district in the north of Stockholm.

The embodied and operational emissions for around 900 existing and planned multi-residential buildings are considered over a time range of 50 years (2020-2070). The interactive tool has been developed, allowing to load data about existing and future buildings, adjust the reference values, configure the interventions, and analyse the WLC impact from individual building pathways and aggregated district scenarios.

The proposed framework allows to obtain a holistic perspective on the WLC of buildings on a city scale. Its bottom-up structure enables analysis of synergies and trade-offs between interventions of various types, be it on a level of a single detailed plan or the whole district development strategy. It also contributes to a better perception of the impact of timing of various interventions aligning with the principles of Dynamic LCA. Hence, it highlights the lifecycle impact of critical choices made in the early stage leading to better decisions.

1.06.B.T-09 Innovating Life Cycle Assessment with Artificial Intelligence: A Generative Pre-trained Transformer Exploration

Kira Fischer, Fraunhofer Institue for Surface Engineering and Thin Films (IST); Nikolas Dilger, Fraunhofer Institue for Surface Engineering and Thin Films (IST); Carsten Schilde, Technische Universität Braunschweig; Christoph Herrmann, Technische Universität Braunschweig.

The relevance of sustainability and artificial intelligence (AI) within society and politics increases exponentially. Within this research the use of generative pre-trained transformers (GPT), particularly ChatGPT, in facilitating the scientific methodology of life cycle assessment (LCA) was investigated. This study focuses on the generation of life cycle inventory (LCI) data with a standard commercial large language model (LLM) on the example of battery anode material, in this case natural graphite. The Life Cycle Inventory is critical for anode materials in batteries as they can account for up to 20% of the total environmental impact of a battery, depending on their mass fraction. The study contrasts two methods: a conventional literature review via Google Scholar and the employment of a GPT to gather equivalent data. The precision, detail, and consistency of the data generated by the standard commercial LLM are subjected to critical evaluation in comparison to the outcomes of the literature research. While AI-generated outputs are beneficial for preliminary drafts and conceptualization, notable inconsistencies emerge. These inconsistencies can be attributed to the inherent limitations of the GPT's training data. The findings indicate that the development of a specialized GPT could enhance the efficiency and accuracy of certain LCA phases, while also reducing the time required for processing.

1.06.B.T-10 Enabling the Mapping of Chemical Substances to Life Cycle Inventory Datasets

Rudri Mankad, PRé Sustainability.

Background and Purpose
Life Cycle Assessment (LCA) studies can help manage the impact of chemicals that are widely used across industries. Data used to model the life cycle of these chemicals is available in Life Cycle Inventory (LCI) databases such as ecoinvent, CarbonMinds and Industry data 2.0. However, this data availability is not without its challenges.

Firstly, there is a lack of uniformity in the availability and granularity of data in these databases. There is also inconsistency in the names and CAS numbers for the same substance. This is compounded by the long bill of materials for chemical-heavy products for which the LCA study is to be done.

The challenge of mapping the bill of materials to the LCI data is well known to LCA practitioners. For a project where a large set of chemicals was to be mapped to LCI datasets, we thus tried to take a systematic approach. This approach and our experience using it are described here.

Method
A mapping approach was defined for the 200 chemicals ("input data"). This can be used with any of the LCI databases; ecoinvent is used as an example.

The input data is first "cleaned" for all of it to be in the same format, by removing extra spaces, for example.

The chemical names in the input data are then mapped to the ecoinvent datasets by performing a "lookup", to identify an exact match. The matching is then done on the similarity of the names in the input data and in ecoinvent using "fuzzy lookup", an Excel add-in.

Comparisons using both product and process names in ecoinvent are done following the above. An order of preference was defined:
1. Match using exact product name
2. Match using exact process name
3. Fuzzy match using product name
4. Fuzzy match using process name

Results
This approach enables a relatively easy, quick, and accurate selection of appropriate datasets to match the substance in the bill of materials, as compared to the manual matching that would be a long, error-prone procedure. However, a quality check of the results is recommended. Data mapping gaps may remain; but that is outside the scope of this study.

Conclusion
The approach addresses the issue related to the mapping of chemical substances to LCI datasets; especially for products with a long bill of materials and a lack of standardisation in naming. Given that the mapping step of an LCA study is one of the most time-consuming steps, this approach provides an alternative that can allow for more studies to be done and for more insights to be generated.

1.06.P - Approaches and Case Studies in Scaling Up LCA

1.06.P-Mo015 ALIGNED D1.2: A Scientific Framework For The Life Cycle Assessment Of Bio-based Products

Massimo Pizzol, Aalborg University; Massimo Pizzol, Aalborg University; Agneta Ghose, Aalborg University; Søren Løkke, Aalborg University; Kíra Lancz, Aalborg University; Marcos Djun Barbosa Watanabe, Norwegian University of Science and Technology; Ugo Watanabe, Institut National des Sciences Appliquées de Toulouse; Damien Arbault, Institut National des Sciences Appliquées de Toulouse; Lorie Hamelin, Institut National des Sciences Appliquées de Toulouse; Maxim Tschulkow, University of Antwerp ; Steven Van Passel, University of Antwerp .

We intend to present the deliverable D1.2 "Description of scientific methods" of the ALIGNED project (Horizon Europe), that proposes the results of the project work to derive a scientific framework for the life cycle assessment of bio-based products – to be applied in the project and more broadly to improve the environmental performance of bio-based industrial activities in multiple sectors.

We reviewed, selected, and further developed and made operational best available methods for the assessment of bio-based products encompassing all the four ISO phases (from goal and scope to interpretation) – the results is a coherent framework that includes approaches, methods, and tools, that can be used consistently together and have high scientific soundness and are evidence-based, with as little normative elements as possible.

In particular the framework includes: methods for generating dynamic background systems for prospective LCA of bio-based products; methods for identification of market constraints to the supply of biomass; methods for time and space-dependent carbon accounting in bio-based carbon uptake and release activities able to return mass balanced carbon inventories; methods and characterisation factors for dynamic assessment of climate change and spatially explicit assessment of biodiversity impacts; methods for uncertainty and sensitivity analysis in bio-based sectors; methods for socio-economic assessment in bio-based sectors. Additionally, methods and tools are provided for sharing and publishing life cycle inventory data, sharing them, importing in software, and enhancing reproducibility and in compliance with FAIR principles and GLAD requirements.

The deliverable D1.2 consists of a series of documents such as guidelines, routines, algorithms, datasets, models, spreadsheets, calculators, codes, and notebooks - all available in open access task-specific project repositories. The presentation will describe the specific purpose and associated content of each part of the methodological framework and provide an overview and map for understanding and navigating the material associated with the deliverable and how to access and use it.

1.06.P-Mo016 Adaptation of Background Lca Databases for Carbon Accounting

Carl Vadenbo, ecoinvent association; Francesco Cirone, ecoinvent association; Johannes Müller, ecoinvent association; Nikolia Stoikou, ecoinvent association; Simone Fazio, ecoinvent association.

Background LCA databases are widely used in carbon accounting as sources for scope 2 and 3 emission factors. Secondary data commonly serve as the fallback option when supplier-specific factors are unavailable or inadequate. They also help identify improvement potentials, set reduction targets and strategies, and aid bench-marking supplier information. With increasing regulatory and stakeholder pressure to disclose and improve the sustainability performance of their operations and products, many companies strive to manage the associated risks by engaging with suppliers and prioritizing credibility and consistency of primary and secondary data sources used.

This presentation covers steps taken to align a background LCA database of global scope with the requirements for carbon accounting. More specifically, it focuses on data needs, methodological adaptations, and solutions implemented for the ecoinvent LCI database. These relate to four important aspects to conform with the GHG Protocol and SBTi standards, namely: i.) the provision of both location- and market-based emission factors for electricity supply, ii.) the scope-dependent separation of scope 2 and 3 emission factors for purchased electricity, including adjusted cut-off point for waste treatment with energy recovery, iii.) the minimum requirements, e.g., in terms of mandatory versus voluntary greenhouse gases, or upstream (scope 3) emission factors for purchased energy from renewable sources, and iv.) emission from Forest, Land, and Agriculture (FLAG) activities. For the latter, we describe a pathway to derive transparent FLAG emissions related to land use change (LUC) . Insights and an outlook for enhanced coverage of emissions from land management are also given.

The effects of these adaptations are compared to the underlying database system model based on quantitative results. The influence of users' decisions to adhere to the minimum requirements or to include further aspects (more closely aligned with a life cycle perspective) is illustrated. Results highlight the need for a transparent and unambiguous system to characterize and reference database adaptations to evaluate or audit the consistency of data from different sources and for communication of reliable results. If feasible by the time of this presentation, the experience from the finalized guidance on FLAG emissions (expected during 2024) will also be provided, highlighting differences to the current implementation of the draft guidance.

1.06.P-Mo017 Testing SSbD Tools for Chemical Substitution: A Walk in the PARC

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The European Commission has presented a framework for Safe and Sustainable by Design (SSbD). In our work, which is part of PARC (https://www.eu-parc.eu/) we have tested a large number of predictive modelling tools. As case study we chose to look at BPA and two alternatives, BPAP and iso-sorbide, in two use cases polycarbonate bottles and epoxy coating. The purpose was primarily to test the tools, i.e. not to find an actual alternative in the chosen use cases. Thus, only the name and structure of the chemicals (CAS Nr) and the intended applications was given, and then tool testers were asked to be explicit about challenges regarding running the tool, as a way to try to understand the applicability of tools in early phases of innovation as possible. For hazard assessment (step 1) we tested the tools VEGA, JANUS, Oncologic, MSC QSAR tool, INTEGRA, Danish Q(S)AR toolbox and OECD QSAR toolbox. For Step 2: Human health and safety aspects of production and processing the following tools were tested: ProScale, INTEGRA, ECETOC TRA, Advanced Reach Tool ART and Stoffenmanager. For step Step 3: Human health and environmental aspects of the final application we tested the tools VEGA, INTEGRA, ECETOC TRA, Consexpo and Simplebox. For step 4 Environmental sustainability assessment we tested the tools quasaLCA and process-LCA (as implemented in GaBi). Social and economic sustainability assessment (Step 5) has so far only been briefly scanned.

Intermediate observations and results include: Tools intended for the same purpose partly align and partly differ in output, also when assessing the same end-point (indicator). The differences in results between different tools seem to be mainly a consequence of methodological and technological choices rather than inherent differences in the tools.

Currently, Steps 1,2 and 3 are much based on the knowledge base in RA, whereas Step 4 is based on LCA. Methods to assess chemical risks in LCA (i.e. toxicity and eco-toxicity potential) are currently not well aligned with the approaches applied in Steps 1-3. There is a need to understand better the relation between Risk Assessment (RA) and LCA.

SSbD has the potential to be a powerful tool for innovation. Predictive models are needed, and are also available, for all steps. Neverthérless, qualitative expert judgement, semi-quantitative models, and computational models, all have an important role to play in all steps of SSbD.

1.06.P-Mo018 Development of an Eco-Design Tool for Life Cycle Footprinting for the Pharmaceutical Sector

Peter Shonfield, Environmental Resources Management; Chris Poulopoulos, Environmental Resources Management; Michael Collins, Environmental Resources Management; Saori Galley, Environmental Resources Management.

Pharmaceutical companies are increasingly interested in understanding the environmental performance of the drug products and devices that they manufacture. Several factors are driving this trend including: developing lower products with reduced burdens, supporting environmental claims, understanding the influence of various impact reduction levers to help meet corporate sustainability targets (eg net zero carbon or SBTi targets), and meeting requests for information from customers, such as healthcare providers.

Conventional LCA studies require specialist software, experienced practitioners with knowledge of the relevant standards and are time-consuming and costly to carry out. This makes LCA difficult to scale and too slow to be useful to support decision making for eco-design activities. Working with leading pharma companies, ERM has developed a life cycle footprinting tool for the pharmaceutical sector that can overcome these drawbacks and provide other advantages.

The tool is structured in a series of modules, each of which focuses on one part of the life cycle: small molecules API, biologics API, formulation and filling, devices and packaging, distribution, and end of life. These modules can be assessed individually or connected to assess the full product life cycle.

Each module is based on a preconfigured model that conforms to the ISO 14044 standard requirements for LCA, so the user need only populate it with data to run results. Results are reported according to the EF3.1 suite of impact assessment methods and provided with a level of granularity that makes it easy to identify the hotspots in the product life cycle.

As well as significantly reducing the time required to undertake assessments, the tool also makes it easy to run alternative scenarios to support decision-making for eco-design and process optimization activities. A further advantage is that no specialist LCA knowledge is required, since the models are preconfigured, so the tool can be accessed and used by a large and varied user community within a company, helping to embed sustainability within everyday business operations.

1.06.P-Mo019 How to Scale up Life Cycle Assessment for Industrial Applications – An Electrolux Group Case Study
Stefano Zuin, Electrolux Italia SpA; Vsevolod Dengin, Electrolux AB; Monica Celotto, Electrolux Italia SpA.

Life cycle assessment (LCA) is a widely recognized method for quantifying the environmental impacts of products or services. However, performing LCA is a complex and time intensive process, especially for business aiming to adopt a scalable approach for several product categories, as appliance industry. This paper aims at sharing the Electrolux Group strategy for conducting scalable LCA and for improving the modelling of life cycle inventory (LCI) data. To this end, an internal survey was carried out with relevant stakeholders having different roles and LCA experience (e.g., R&D engineers, managers, etc.) to highlight main barriers for scaling the LCA and to better understand their needs. Feedback from survey highlighted that the main barriers for scaling up LCA in Electrolux are: i) time and resource management; ii) complexity reduction; iii) collection and processing of LCI data; iv) user/staff knowledge; and v) accessibility/democratization. According to stakeholders need and tools used in the company, an LCA-based dashboard and a customized LCA calculator were then developed to address those barriers. Although there have been several data sources at hand in past Electrolux LCA studies, e.g., bill of material (BOM) of appliances, use scenarios, etc., we never organized all the different information into a complete picture through a LCA tool. Now with the dashboard, the business users may extrapolate LCA-related data and results from LCA studies. This dashboard also simplifies the scenario analysis because defined parameters can easily be varied by users (e.g., change the energy mix). Concerning the spreadsheet based LCA calculator, it was developed to speed up and harmonize LCA studies, as well as to automatize certain parts of the LCA, e.g. automated calculation of results and BOM integration. The customized LCA calculator contains LCI database, default scenarios, and has a modular approach. The motivation for automation was to reduce the time and effort required to collect and process LCI data, especially the automated integration of BOM. This work focused on approaches that addressed the barriers for scaling up the LCA in Electrolux Group. The benefits associated with the execution are evident. However, other challenges remain, especially to integrate and connect to various company product life cycle management systems, including databases to reduce the effort for data handling and interpretation.

1.06.P-Mo020 Site-Specific Life Cycle Inventories of Offshore Wind Farms Computed With Limited and Flexible Input Data for Multiple User Profiles
Joanna Schlesinger, MINES Paris - PSL; Raphaël Jolivet, MINES Paris - PSL; Manel Sansa, France Energies Marines & Schneider Electric ; Paula Pérez-López, MINES Paris – PSL.

Offshore wind power is experiencing fast development in the last years and the global installed capacity is expected to be multiplied by four in the next decade. The demand for environmental assessments of offshore wind farms, mainly using Life Cycle Assessment (LCA), is quite recent and also rapidly increasing. However, access to data to conduct these LCA might be limited because of confidentiality, time constraint, data scarcity for projects at early stages of development. Some potential users of LCA results (eg public stakeholders or design engineers) might also not have access to this data.
In this work, an approach is proposed to generate site-specific Life Cycle Inventories (LCI) and mass balance of offshore wind electricity production rapidly as a limited set of input data is required and in a flexible way. It is flexible thanks to the possibility to adapt the required data used as inputs for multiple user profiles.
A parameterized LCI model in python language for an offshore wind farm has been developed with a cradle-to grave approach. The model's user enters input data about the farm to be modeled. The model can be used at three different levels depending on which data is at the user's disposal.
At the "easiest" level of use, the user provides 20 parameters' value on the modeled farm such as nominal capacity of turbines, water depth, foundation type... The results generated consider site characteristics such as turbines and foundations size or technological choices. At intermediate and expert levels, the user enters more input data, such as mass of turbine's main parts.
The possibility to use the model at these three levels enables the valorization of specific data, whenever available to get more specific results, but makes it possible to get rough estimates even for cases where data is scarce.
The steps to develop the model were:
1 identifying the main site-specific parameters that affects LCA results
2 generating a parameterized LCI model based on a limited set of parameters by using LCIs from literature and aggregated mass data
3 designing the model to introduce several levels of use to be adaptable according to the input data at the user's disposal
This case study shows that parameterized LCA models can be structured with different levels of use. Such implementation valorizes available data from existing industrial projects to meet the need of rapid, flexible screening LCA for future projects.

This work has been conducted in the frame of the project LIF-OWI [2021-2023] which was financed by ADEME, France Energies Marines and ANR (n° ANR-10-IEED-0006-34).

1.06.P-Mo021 Hybrid Real Time Lca for Performance Monitoring in Mineral Extraction and Processing Facilities
Pavel Stránský, SINTEF Helgeland AS; Tazrin Ahmed, SINTEF Helgeland AS.

Life cycle assessment (LCA) methods are increasingly being suggested for monitoring environmental performances in the mining sector. These methods provide comprehensive insights into the environmental impacts of mining activities, helping to identify areas for improvement and drive sustainable practices.

The DINAMINE project, supported by European Union's Horizon Europe research and innovation programme (Grant Agreement No. 101091541), aims to improve the mining industry through the integration of digital technologies such as robotics, artificial intelligence, and automation. These technologies will enhance the efficiency and sustainability of small and medium-sized mines, supported by a comprehensive mine management system known as the Integrated Smart Mine Planning and Managing (ISMP) system.

The ISMP system is central to the project, providing a state-of-the-art platform for data collection, management, and visualization. It includes modules like the Mine Information Model, Tailing Information Model, and Mineral Processing Model, among others. The system visualizes important mining parameters and employs a traffic light system for simplifying day-to-day operations.

A significant aspect of this project involves collaboration with mine operators and project participants to determine the most relevant sensors for real-time measurement. Gamification elements are incorporated to engage plant operators, allowing them to compete on various LCIA metrics. Additionally, Exiobase-provided indicators are used to integrate social aspects into the assessments.

The methodology developed employs a hybrid input-output life cycle assessment (I-O LCA) framework, integrated with EXIOBASE data and life cycle impact assessment (LCIA) methodological choices. The MARIO Python package is used to manipulate the background database such as aggregation of sectors or geographical locations. By combining process-based LCA databases for assets acquired prior to the years covered by EXIOBASE, a dynamic assessment that integrates both process-based and environmentally extended input-output (EEIO) databases is achieved. This approach addresses the challenge of discounting global warming potential values for assets produced in different years than the process-related emissions.

This dual approach allows for real-time identification of environmental impact hotspots, enabling immediate and targeted interventions. The hybrid I-O LCA framework, in conjunction with the MARIO Python package and EXIOBASE data, demonstrates faster response times compared to traditional LCA reporting systems, allowing for more timely decision-making and adaptive management practices within the mining sector.

While the methodology presents significant advancements, challenges remain. These include integrating process-based and EEIO databases, managing data resolution discrepancies, and addressing skewed results caused by irregular use and early retirement of assets. Despite these challenges, the potential for real-time, dynamic environmental assessments offers a promising avenue for enhancing the sustainability and efficiency of mining operations. The insights gained from this research provide a foundation for further refinement and adaptation of LCA methodologies in the mining sector and beyond.

Track 2: Life Cycle Impact Assessment

2.01 - Advances in Life Cycle Impact Assessment

2.01.A.T-01 Characterize Chemical Toxicity for Life Cycle Assessment Using Machine Learning Models Based on Environmental Footprint

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The current toxicity life cycle impact assessment methods, i.e., USEtox and the recent development of Environmental Footprint 3 (EF3), calculate characterization factors (CFs) for only limited amount of chemicals, which are far from covering whole range of commercial chemicals to which humans may be exposed. Filling this gap becomes paramount for regulation and safeguarding human health and ecosystems, but faces challenges in data collection. The previous literature mainly tackles this issue by learning from USEtox CF and corresponding chemical properties, while the recent development of EF3, which provides a new dataset that contains around two times data entries then USEtox, has not been used for training ML models. This work aims to fill this gap by first developing a framework and then using this framework to train different ML models and predict CFs based on EF3.

The framework starts by generating Simplified Molecular Input Line Entry Specification (SMILES) for chemicals in EF3, followed by generating descriptors, data curation, clustering, and training. The framework was used to predict midpoint ecotoxity CF for emissions from continental freshwater using three ML models, i.e., XGBoost, gaussian process, and neural network, with coefficient of determination (R2) values 0.55, 0.54, and 0.5, respectively, as their performance indicator results, which indicates a similar prediction accuracy among these models. Cluster-specific R^2 show a large variance, which indicates that the trained models based on overall dataset are more reliable for certain clusters of chemicals than others.

This study embarked on a required quest to harness ML in bridging data gaps inherent in the toxicity characterization of chemicals, a pressing need amid the burgeoning array of chemicals in the market. Through the adept application of ML algorithms, namely XGBoost, gaussian processes, and neural networking, this research is working on predicting chemical toxicity more broadly, leveraging on the latest EF 3 data and methodologies. While preliminary, our results indicate that our model can serve as a tool to predict CFs for new chemicals of certain types. Future work should focus on improving the selected algorithms, refining the clustering methodology, and exploring different neural network architectures to enhance predictive performance across all clusters. Finally, further steps in this study will include the exploration of other characterization factor prediction, e.g., human health toxicity.

2.01.A.T-02 Development of a Life Cycle Impact Assessment for Zoonotic Disease Spillover Risk in Animal Agriculture

John Hader, Swiss Federal Laboratories for Materials Science and Technology (EMPA); Nadia Malinverno, Nadia Malinverno, Empa; Claudia Som, Empa.

Emerging infectious diseases largely circulate in wildlife, and while they can pose a direct risk to humans, they are often limited in their transmissibility from wild animals to humans. Farmed animals, however, can act as an intermediary for viruses between wild animals and humans, resulting in new variants of the disease that can more easily "spill over" into humans. Life Cycle Impact Assessment (LCIA) attempts to understand the environmental impact of different animal-derived products. While LCIA methods exist for e.g., greenhouse gas emissions and land use, no such LCIA method exists for quantifying how different types of animal farming practices, and the activities along each step of the supply chain, contribute to an increased risk of zoonotic disease spillover. Our aim is to develop a framework for a (semi-)quantitative LCIA of the risk of a zoonotic disease spillover from wildlife into humans due to animal agricultural practices, relative to a baseline of no animal agricultural practices. We will conduct a modelling analysis of hypothetical chicken farming operations reflecting practices in three countries with high chicken production (USA, Brazil, and China) and two production methods (an intensive, more biosecure operation; and an extensive, less biosecure operation). A scenario where no chicken farming is taking place will also be simulated, whereby spillover of the virus could only occur through wildlife–human contact. For each scenario, a modified version of a population viral infection model will be used to simulate a hypothetical virus circulating in wildlife that can spill into a farmed animal population, mutate, and cross into humans. Literature will be reviewed to obtain values for necessary parameters, such as agricultural practices in each region, virus mutation rate, and wild–farmed animal contact frequencies, based on wildlife data in each geographical region. Our preliminary analysis will be a starting point for the incorporation of zoonotic disease spillover risk into the LCIA of agricultural practices. While beyond the scope of this study, long-term goals are also to assess the Disability Adjusted Life Year impacts on humans, as well as potential effects on ecosystem quality from amplified diseases re-introduced into wildlife. An LCIA for zoonotic disease spillover would provide a more comprehensive picture of the sustainability of different animal products, and further inform dietary decisions by the public and policy makers.

2.01.A.T-03 LCA Modelling of the Environmental Impacts of River Sand and Aggregates Mining

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Mainly used in the construction sector, sand and gravel (hereafter named aggregates) account for 68% of non-metallic materials extracted worldwide. Global demand for aggregates sharply increased during the last century, part of which is extracted from rivers. The impacts of river aggregates extraction range from changes to the hydro-geomorphological functioning of rivers, to modification and direct destruction of aquatic habitats, turbidity, pollution, scouring of structures, etc. This proposal aims at (I) characterizing and classifying environmental impacts related to river aggregates extractions, (II) defining a methodological framework to account for the hydrogeomorphological impacts associated with such extractions, in a Life Cycle Assessment (LCA) perspective.

We propose a characterization and classification of extractions based on two parameters: extraction zone and extraction technique. The impacts associated with river aggregates extraction for a given technique and zone are organized into four interdependent categories: impacts on the physical environment, on the natural environment, on the landscape and human impacts. The physical (hydro-geomorphological) impacts are more specifically described in terms of upstream erosion, downstream erosion, lateral instability and bed and banks coarsening.

Based on this categorization of impacts and considering existing life cycle impact characterization models, we define a methodological framework for the modelling of hydro-geomorphological impacts at midpoint level. A modelling of the causal chain from minor river-bed extraction to incision and subsequent lowering of the water table is proposed. It links a mass of aggregates extracted from the minor river-bed to a water deficit per surface unit. Two sub-models are used: one to describe the topography of the valley, the other the lowering of the water table. The model is tested for a simple configuration. It describes the evolution of the river profile as a function of time and the evolution of local groundwater deficit as a function of the mass of aggregates extracted from the minor river-bed.

This work sets the basis for the characterization of impacts of aggregates extraction in rivers. Particular attention should be paid to archetypes of extracted aggregates, considering river and climate types, extraction zones and extraction techniques. Another challenge is to have the corresponding elementary flows available in life cycle inventories.

2.01.A.T-04 Ionizing Radiation Potential in Life Cycle Impact Assessment Through the Lens of Radiological Protection

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Life cycle assessment has been implemented to compare nuclear electricity production with renewable energy sources; the ionizing radiation potential (IRP) impact category is primarily modeled using the human health damages (HHD) methodology published in 2000. To date, very few updates have been made to the HHD methodology despite limitations of the model. Two new impact assessment methodologies, UCrad and the critical group method, were introduced in 2020 to address limitations such as the site-specific data dependence in the HHD methodology.

This work aims to evaluate the fate, exposure, and effect modules of the UCrad methodology from a radiological protection perspective and to address identified gaps in computing the IRP. One of the main methodological critiques is the exclusion of radiological decay products (progeny); proposing a method to address this required characterization factors (CFs) to be recalculated. In order to ensure transparency to LCA and non-LCA practitioners alike, the equations used were comparable to (1) methods established for other impact categories and (2) those used in radiological risk assessment. USEtox was used to determine the environmental steady state concentrations (consistent with the UCrad approach).

Preliminary results indicate that CFs reported herein result in a lower impact for select nuclides than those reported in UCrad, particularly for increasing time. For example, 10,000 years after the release 102, 98, and 96 radionuclides (of 113) have CFs smaller than those reported in UCrad. For a subset of those radionuclides, the damage factors relative change between the time-averaged approach with and without progeny shows that Bi-212 progeny changes impacts from an atmospheric release by 84.5% at all timehorizons. Other radionuclides (such as Ra-226 and U-235) have small changes at lower timehorizons, that become more pronounced as time increases (e.g., up to 87.2% relative change for Ra-226 at 10,000 years or 80.1% for U-235 at 10,000 years). Thus, the timehorizon and progeny inclusion can have drastic impact implications.

To the authors knowledge, this is the first research to propose a method for including progeny in the IRP methodology. Due to the use of USEtox steady state concentrations coupled with radiological risk assessment equations, this methodology allows for comparison between chemical and radiological emissions while seeking to support a broader application and expanded influence of LCA studies.

2.01.A.T-05 Identification of Dissipative Forms of Carbon in End-of-life Plastics

Thulangi Gayathma Balasuriya, Technical University of Denmark (DTU); Stig Irving Olsen, Technical University of Denmark; Michael Zwicky Hauschild, Technical University of Denmark; Mikolaj Owsianiak, Technical University of Denmark.

Carbon is the backbone of many organic compounds, including plastics, and plays a pivotal role in the economy. Current methods for accounting for carbon resource use in environmental sustainability assessments of products and technologies have traditionally focused on depletion. However, the implementation of circular economy principles requires approaches which consider carbon dissipation and its accessibility as a resource for future generations. Therefore, this study aims to present a new method for identifying dissipative carbon forms in end-of-life plastics. It considers dissipation mechanisms that relate to the thermodynamics of chemical recycling through depolymerization. We studied 23 polymers commonly used in the production of plastic products. Using the ceiling temperature of the depolymerization reaction as the criterion determining whether or not depolymerization reactions are plausible, we identify dissipative forms of carbon in each polymer. Results indicate that carbon in one out of 23 polymers is dissipative while it is potentially non-dissipative in the remaining 22 polymers concerning the biomass-ethylene system. In the context of the crude oil-useful carbon system, 13 polymers are dissipative, while the remaining 10 polymers are non-dissipative. Thus, in contrast to depletion-oriented accounting approaches where all carbon is considered equal, not all carbon forms in end-of-life plastics are dissipative. These differences should be considered in accounting of resource use in environmental sustainability assessments. Our approach can be used to support the identification of optimal management routes for end-of-life plastics.

2.01.B.T-06 Absolute Sustainability of Mineral Resource Use: A Way Forward

Katarzyna Dudka, Technical University of Denmark (DTU); Michael Zwicky Hauschild, Technical University of Denmark; Mikolaj Owsianiak, Technical University of Denmark.

In Absolute Environmental Sustainability Assessments (AESA) environmental impacts attributed to a product system are compared to its assigned share of a carrying capacity (also referred to as boundary or sustainability reference). For the climate and ecosystems, boundaries are well established, while for mineral resources, the definition of boundaries is not straightforward. This is because mineral resources are often seen as indestructible or renewable and play an instrumental role from a human perspective. Due to the various techno-economic aspects involved, different views exist on what it is that we actually want to protect when addressing mineral resources in sustainability assessments (this is also referred to as the area of protection). Several attempts at defining absolute sustainability boundaries for mineral resources have been made. However, the existing boundaries are expressed in different metrics and scattered across research areas. It is, therefore, relevant to collect, compare, and evaluate existing definitions. For this purpose, we carried out a systematic literature review of existing absolute boundaries for mineral resource use, defined criteria for their inclusion in the review, defined a baseline for each parameter needed for conversion, and expressed each of the existing boundaries relative to this baseline to enable quantitative comparison. The compared boundaries expressed in tonnes of raw material consumption vary by more than 2 orders of magnitude in the year 2050. This variation mainly reflects different views on how boundaries should be defined. We further evaluated the existing boundary definitions using established criteria for the definition of environmental boundaries and identified several challenges. The identified limitations concerning the area of protection and other design parameters dependent on it highlight the need to rethink if and how an absolute sustainability boundary for mineral resource use should be defined.

2.01.B.T-07 Absolute Environmental Sustainability Assessment of Aviation Transition Scenarios

Bastien Païs, ISAE-SUPAERO; Alexandre Gondran, ENAC; Lorie Hamelin, Toulouse Biotechnology Institute; lorian Simatos, ISAE-SUPAERO.

Background and purpose

The aviation sector is currently responsible for 2-3% of annual anthropogenic CO2 emissions and for 5-6% of the recent climate impact. In order to assess its climate footprint over time, the sector and its various stakeholders have developed numerous prospective scenarios incorporating different assumptions about traffic growth, fleet renewal, introduction of new technologies, and the use of alternative fuels. However, the various solutions proposed are only assessed through the prism of climate.

By reducing the scale from global to sectoral, the Planetary Boundaries (PB) framework can be used to perform an Absolute Environmental Sustainability Assessment (AESA) of contrasted prospective scenarios for the aviation sector.

Based on recently developed tools and methodologies, this study brings methodological and conceptual advancements to enable dynamic and prospective AESAs and present applications to aviation prospective scenarios.

Methods

This study uses and develops the PB-LCIA methodology, which links LCA to the PB framework. By using the premise tool and developing a dynamic approach to impact assessment, it develops a new methodology for prospective and dynamic AESA.

It also deploys and develops the “Fulfilment of Human Needs” approach of Heide et al. which is based on the notion of sufficientarianism to share PB budget between different human activities.

Results

Historical aviation (1940-2022) already exceeds its PB budget for climate change, biosphere integrity, and nitrogen cycle. Scenarios using alternative fuels have a lower climate impact than the 100% fossil fuel scenario, but generate new potential environmental problems, such as the disruption of the phosphorus cycle. Among the 217 scenarios studied, none can be classified as absolutely sustainable.

Conclusions

By using new tools and developing an appropriate methodology, our work highlights the potential and the limits of alternatives fuels to reduce the environmental impacts of aviation. It also shows the absolute environmental unsustainability of the aviation sector. Furthermore, the development of this methodology opens the possibility of conducting prospective and dynamic AESAs for other sectors of activity, enabling the anticipation of sustainability issues as well as the displacement of environmental problems in a context of decarbonization of activities.

2.01.B.T-08 Investigating Key Methodological Aspects in Absolute Environmental Sustainability Assessment

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Absolute environmental sustainability assessment (AESA) is an emerging approach that enables identifying those systems that are inherently environmentally sustainable by combining Life Cycle Assessment (LCA) with absolute limits, most commonly represented by the Planetary Boundaries (PBs) framework. The ability to assess the absolute environmental sustainability of a product system is paramount because although we are improving the environmental performance of individual products, the total environmental impacts of our society continue increasing due to growing population and per capita consumption. For this reason, AESA is attracting increasing attention in academia and beyond, including for policy-making.

One potential obstacle to the widespread uptake of AESA is the lack of a consensus methodology. In this work we focus on two key methodological aspects: i) how to harmonize LCA indicators with the PBs control variables, and ii) how to allocate the Safe Operating Space delineated by the PBs to individual systems. We compare existing literature approaches and investigate their qualitative and quantitative differences, using as a case study the EU Consumption Footprint developed by the Joint Research Center (JRC). The harmonization aspect is investigated via three approaches that address different steps of the life cycle impact assessment stage. The allocation aspect is explored via four alternative approaches, representing those that are most commonly adopted. The work unveils significant differences between the methods to harmonize LCA and PBs, not only in terms of PBs covered but also in terms of the results obtained. The results also highlight the significant sensitivity of AESA results to the allocation principle, suggesting the need to consider multiple allocation principle in AESA studies.

2.01.B.T-09 Regionalized Impact Calculation in openLCA: Case Study from the Flexby Project Preliminary Life Cycle Assessment

Sarah Serafini, Greendelta; Andreas Ciroth, Greendelta; Michael Srocka, Greendelta.

Accurately assessing localized impact categories is one of the main challenges in the Life Cycle Assessment (LCA) field. Certain impact categories, like water and land strass, necessitate calculations that consider specific local conditions to achieve accurate assessments, being the impacts inherenly localized. Regionalised Life Cycle Impact Assessment (LCIA) is now increasingly available in LCA software tools.

To show the effect of regionalized impact assessment, we conducted a comparative study of the water scarcity footprint of a process occurring in Andalusia (Spain) using the new regionalized calculation feature provided by openLCA. This evaluation was conducted as as a part of Flexby project (funded by European Union) prelimirary LCA. The aim of Flexby is to to carry from Technology Readiness Level 3 to 5 the production of sustainable gaseous and liquid biofuls produced with microalgae grown on domestic wastewater and oily industrial sludge. Andalusia, experiencing greater water scarcity compared to the Spanish weighted aggregation, served as a prime example. We used openLCA v2.1.1 as LCA tool and ecoinvent v3.10 as database. We imported the shapefile of AWARE in openLCA and used it to calculate the Characterization Factor (CF) for Spain as country and then for Andalusia, then specified the two different location for the same process and run a regionalized calculation to assess the water stress generated by both processes. The region-specific assessment yielded a more accurate evaluation (1.30139 m3 world-eq vs 2.49414 m3 world-eq) underscoring the importance of regionalization in achieving reliable and relevant LCA outcomes.

Several LCIA methods have been using geospatial data files (e.g., AWARE 1 and 2, LC-IMPACT, etc.) that bind the CFs to local characteristics at the sub-country level; Implementing these methods in software as intended by researchers makes these methods broadly available and practically applicable. Moreover, by tailoring calculations to the regional specifics of the affected areas, we achieve not only enhanced precision but also several other key benefits. For instance, regionalization can streamline data management and analysis by reducing the number of flows required in the database.

Our findings emphasize the critical role of regionalized calculations in LCA. By tailoring impact assessments to local conditions, we can achieve more accurate and relevant outcomes, ultimately supporting better environmental decision-making.

2.01.B.T-10 Local Impact Assessment and Valuation of Tunicate Farming

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Background and purpose: Food production and consumption is a main cause of many environmental problems. Low-trophic level aquaculture has emerged as a promising technology to provide food and feed with a low impact. Tunicate is a marine invertebrate that can be used as human food or feed for salmon. A pilot facility has been operating in the west of Sweden since 2015 and scale up is planned for several locations in Norway. The tunicates feed on plankton, which are in abundance in the Skagerrak strait between Norway and Sweden due to nitrogen runoff from agriculture and effluent from wastewater treatment. The farming of tunicate withdraws nitrogen from the ocean and can thus reduce the eutrophication. The purpose of the work is to find appropriate ways to address this nitrogen removal effect by applying life cycle impact assessment.

Methods: The scope of study to further investigate the potential for tunicate farming as an environmentally sustainable food is to focus on local impact factors and valuation of different impact categories. Inventory data was based on previous studies, but updated with recent data from the case company. The study has two experiments. The first to find relevant impact assessment methods of marine eutrophication at sub national level. The second to evaluate the importance of marine eutrophication to other impacts with economic valuation.

Results: Two approaches to local impact assessment of marine eutrophication was found and that had characterisation factors at sub-national level. In one of the methods the variance in impacts did not change that much, while in the other methods the impact factor changed by more than an order of magnitude. One difference between the methods are that the second has a greater spatial diffrentiation. The results from valuation of impacts from tuniacte farming show that the reduced eutrophication result in a total net negative cost. The tunicate burger pilot recipie also has other ingredients of vegetable origin that outweights the benefits of tuniacate farming on marine eutrophication and thus net positive cost.

Conclusions: The experiments in this study indicate that tunicate farming can reduce marine euthrophication, but impacts of other ingredients in a burger patty can outweight the benefits. Local characterisation factors on sub national level are however needed and further studies should combine this with economic valuation.

2.01.P - Advances in Life Cycle Impact Assessment

2.01.P-Mo022 Climate Tipping Impacts of Short-Lived Forcers

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Background and Purpose: Recent developments in life cycle impact assessment include a new method for calculating climate tipping characterization factors of carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O). The method covers 13 projected tipping points, incorporates the effect that the crossing of a given tipping point has on accelerating the crossing of other tipping points, and addresses uncertainties in the temperature thresholds that trigger the tipping points.
Methods: Here, we further adapted this climate tipping modelling framework to characterize short-lived climate forcers, with the hypothesis that they have significantly higher potential to contribute to crossing climate tipping points when compared to the long-lived greenhouse gases.
Results: Tentative results show that new climate tipping potential (MCTP) of short-lived non-methane volatile organic compounds (NMVOCs) like ethanol, halocarbons like HFC-152 and black carbon are equal to 0.015, 0.040 and 20.7 ppt/kg respectively for an emission in 2050. These values generally exceed those calculated for CO_2. Further, the MCTP of the NMVOC isoprene is 4 times higher for emissions in 2050 compared to 2025, while that of CO_2 is 2 times higher.
Conclusions: This demonstrates that short-lived forcers are particularly significant stressors from the perspective of climate tipping.

2.01.P-Mo023 Evaluating Economic Sustainability in the Emerging Bio-Economy: Monetary Valuation of Environmental Impacts for Informed Decision-Making

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In the transition to the circular bio-economy, bio-based products encounter challenges in market competitiveness compared to conventional fossil-based counterparts, due to the higher costs of research, the equipment needed in the production processes and the lower degree of technical development. Conversely, these products offer different advantages, such as reduced raw material cost by using waste as inputs (secondary raw material) and potential reductions in environmental impacts across the entire life cycle.

In the context of addressing these challenges and opportunities, the BIOMAC project, a Horizon2020 initiative, aims to establish an Open Innovation Test Bed (OITB) focusing on upscaling technologies by using nano-enabled bio-based materials (NBMs) for diverse market applications. One of the main tasks of the BIOMAC project is to evaluate the environmental and economic viability of innovative bio-based production processes at a pilot scale, from the biomass pretreatment to the final product. The primary approach involves utilizing Life Cycle Assessment (LCA) and Techno-Economic Analysis (TEA) at pilot scale of the project, strategically identifying and prioritizing critical environmental and economic aspects considering different biomass sources before industrial implementation. In addition, the challenge of evaluating future costs and revenues at the initial stages of a project will be addressed, considering uncertainties in prices and impending regulations related to emissions limits and environmental protection. This holistic approach seeks to enhance decision-making for project development by providing a nuanced understanding of both environmental and economic dimensions.

The research makes a distinctive contribution by proposing an integration of sustainability aspects using the Life Cycle Costing (LCC) methodology to monetize LCA results. This approach ensures that environmental impacts are not relegated to post-investment considerations, granting decision-makers greater flexibility for environmental improvement. By extending the TEA boundaries in the LCC including the monetary valuation of environmental impacts, the project contributes to a more holistic assessment of developments within the bio-based value chain. The importance of this scientific innovation lies in offering stakeholders a broader scale analysis of the potential economic advantages associated with sustainable innovations, bridging the gap between environmental considerations and financial analysis.

Determining the optimal plant capacity and unitary production costs will be the basis for evaluating both environmental and economic impacts from pilot to industrial scale. This assessment identifies critical hotspots that producers must consider during the upscaling of their technologies. LCA results will be integrated into the cash flows as external costs for the calculation of financial indicators such as Net Present Value (NPV), Internal Rate of Return (IRR), and Return on Investment (ROI) for bio-based production processes. Moreover, conducting sensitivity and uncertainty analyses on various parameters enhances the robustness of the assessment, accounting for potential risks in future cash flows.
The comparison of the results with the fossil-based production processes including the monetary values of the environmental impacts in the calculation of the NPV and other financial indicators will determine whether the innovation represents an improvement considering sustainability and feasibility over conventional processes. Therefore, this research will underscore the significance of developing sustainable and circular processes in the bio-economy, highlighting how the monetary valuation of environmental impacts can serve as a catalyst for facilitating access to funds essential for investing in the transition to cleaner production technologies.

2.01.P-Mo024 Attributional and Consequential Life Cycle Assessment for a Green Industrial IT

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Context and goal
Climate change is a global concern. Awareness of environmental issues has prompted international organizations to introduce stringent measures offering manufacturers opportunities for competitiveness, sustainability and innovation. Today, the standardized Life Cycle Assessment (LCA) tool (ISO 14040, ISO 14044, 2006) is used to accurately assess an entity's environmental impact. However, we distinguish between two distinct approaches: attributional and consequential. It was found that there were confusions that made the implementation of the second approach more complex. This work enables us to study how the two approaches work, so that we can respond differently to the same type of question, such as "what would be the consequences of changing the cooling system? The challenge is therefore to generate new knowledge on the approaches by exploring them in a highly controversial sector of activity.

Material and method
This study constructs a comparative method for the environmental impacts of different computer cabinet cooling system processes. The methodology uses the LCA method, through scenarios. The attribution method consists in assessing the impacts generated by the production of different cooling systems evolving on a time scale: Air Cooling, Direct Liquid Cooling and Immersion Cooling. The analysis comprises three phases: material extraction, manufacturing and product use. This clarifies the stages influencing the analysis results. Using economic models, the scenarios of the consequential approach are based on a change of technology, including a temporal evolution: from Air Cooling to Direct Liquid Cooling and from Air Cooling to Immersion Cooling. The study examines how to assess the environmental impact of industrial IT equipment on energy, resources and global warming.

Results and conclusions
The results of this comparative analysis are divided into three axes: the first expresses the LCA results of each cooling system to compare them with each other using the attributional approach. The second examines the LCA results of a technology change using the consequential approach. This will then enable the environmental footprints of each approach to be represented separately, on the Biosphere and the Technosphere. Finally, the last section aims to compare the differences and similarities resulting from the evolution of the Biosphere and the Technosphere, to confirm or refute the complementarity of the two approaches.

2.01.P-Mo025 Multi-Objective Optimization of Environmental Impacts of Bio-Based Industry Production Processes: A Case Study

Alejandro Álvarez, Contactica; Tamara Coello García, Cesefor; Merlin Alvarado-Morales, Technical University of Denmark; Eduardo Entrena Barbero, Contactica.

This work presents a Multi-Objective Optimization (MOO) framework that is applied to a specific case study in a Spanish context of the woodworking sector: the hot-pressing process of Laminated Strand Lumber (LSL) boards, which is one of the production processes to be evaluated within the CALIMERO project. The main objective is to simultaneously improve the two of the three dimensions that make up sustainability: environment and economy, focusing on the reduction of both environmental and economic burdens simultaneously. The MOO algorithm, which is at the heart of the framework, is based on evolutionary algorithms that allow the exploration of trade-offs between conflicting objectives by generating a set of solutions known as the Pareto front.

With such a purpose, the study is focused on a life cycle purpose, conducting a Life Cycle Assessment (LCA), apart from a Life Cycle Costing (LCC). According to the LCA, up to 16 different environmental impact categories are considered which are encompassing within the Product Environmental Footprint (PEF) methodology (e.g., climate change, water use, etc.), following an attributional cradle-to-gate approach. According to the LCC, primary data from industrial stakeholders is gather for estimating the operational expenditures (OPEX) of the manufacturing process.

The associated emissions are taken into account by simulating the production process using dedicated software and by varying the operational parameters that influence the final result (i.e. the LSL boards). In this sense, the 16 PEF impact categories, together with OPEX, serve as targets for the MOO algorithm. Through iterative optimization, the MOO algorithm navigates the space of operational parameters to identify a finite set of solutions that minimize all objectives while maintaining balance. This ensures that improvements in one area do not come at the expense of compromising performance in another.

The case study presented demonstrates the applicability and effectiveness of the MOO framework in addressing complex sustainability challenges, such as finding a balance between environmental sustainability and economic feasibility of specific production processes. An example of a forest product is presented. However, through further iteration and refinement, this can be applied to several additional case studies.

2.01.P-Mo026 Life Cycle Assessment of Wood-based Hydrophobic Coating Materials
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Developing new processes to produce bio-based chemicals, which can replace fossil-based alternatives, is crucial for addressing today's global challenges. However, as biomass usage for new applications grows, it's important to remember that biomass, despite being renewable, has sustainable limits due to land availability, material constraints, and other sustainability factors. There is a need for safe and sustainable alternatives for hydrophobic coatings in the textile and packaging industries. Bio-based coatings are promising in this regard. While traditional wood coatings, like oils and waxes, have been used, they often lack durability. Bark biomass-derived materials such as suberin, lignin and betulin are biopolymer and used as raw materials for producing the hydrophobic coatings. It is important to know the environmental impact of hydrophobic coating treatments process and their production before upscaling the research. Life cycle assessment (LCA) used to assess the GHG emissions of these hydrophobic coating from cradle to gate and their applications. The primary data were collected from laboratory experiments, and secondary data were taken from the literature and the ecoinvent 3.9.1 database. The functional unit was used one m2 of biobased coating material and IPCC 2007 method was used for calculating the global warming potential (GWP). The results showed that the GWP for lignin-based coating was 1.84 Kg CO2 eq., GWP for betulin based coating was 1.95 Kg CO2 eq. and GWP for suberin based coating was 2.03 Kg CO2 eq.

2.01.P-Mo027 Integrating Bim and Lca for Sustainable High-Speed Rail Infrastructure: A Framework for Early Design Stage Environmental Assessment
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Background and Purpose:

The construction and infrastructure sector significantly contributes to environmental impacts at both local and global scales. In response to the climate emergency, there is an urgent need for methods that reduce the environmental footprint of this sector. Building Information Modeling (BIM) is a promising approach, facilitating collaborative work through a 3D model enriched with structured objects. This research focuses on integrating Life Cycle Assessment (LCA) with BIM to evaluate the environmental performance of railway infrastructure projects from the earliest design stages. The goal is to enhance the interoperability between BIM and LCA tools to optimize the design and reduce environmental impacts throughout the infrastructure's life cycle.

Methods:
The methodology involves several key steps:

Literature review: A thorough review of existing studies on BIM and LCA integration and environmental performance assessment of railway projects.

Data collection: Gathering relevant data on railway projects, including design information, material specifications, energy consumption, and maintenance needs from project documentation and sectoral databases.

Development of BIM-LCA integration framework: Creating a framework for integrating BIM and LCA tools, focusing on data synchronization, compatible LCA databases, and automated information exchange to enable real-time environmental performance calculations.

Environmental performance calculation: Using the integrated BIM-LCA framework to calculate environmental performance indicators for railway bridge projects, such as carbon footprint, energy consumption, water use, and waste generation.

Sensitivity analysis: conducting sensitivity analyses to evaluate the impact of different design and operational parameters on environmental performance, aiding in identifying key factors influencing environmental outcomes.

Case studies: applying the methodology to real-world railway bridge projects to assess environmental performance and compare results with traditional assessment methods.

Validation and verification: ensuring the accuracy and reliability of the methodology through validation against actual project data and verification exercises.

Preliminary Results:
Using an integrated BIM-LCA approach, major environmental implications during the material manufacture and construction phases of a high-speed rail bridge project were discovered. The construction of structural components and equipment was found to be 40–60% responsible for the overall environmental impact in several categories, such as greenhouse gas emissions, acidification, eutrophication, and non-renewable energy consumption, according to an analysis conducted using OpenLCA and the Ecoinvent 3.7.1 database.
Notably, a significant amount of these effects were caused by the manufacturing of concrete parts like piles, beams, and deck slabs. These results highlight how crucial it is to focus on material production processes in rail infrastructure projects in order to reduce their negative environmental effects.

Conclusions:
The integration of BIM and LCA in the early design stages of railway infrastructure projects offers significant potential for reducing environmental impacts. By enabling real-time environmental performance calculations and facilitating data exchange between BIM and LCA tools, this approach supports sustainable infrastructure development. The findings of this research demonstrate the feasibility and benefits of the integrated methodology, providing a foundation for further research and practical implementation in the construction industry. The development of compatible LCA databases and the enhancement of data interoperability are essential steps toward achieving these goals, contributing to more sustainable and environmentally friendly railway infrastructure.

2.01.P-Mo028 Optimizing Decision-Making for Heating System Retrofit in Residential Buildings through the Application LCSA
Nao Shibata, University of Reading.

The residential sector consumes over half of the energy in the construction sector, necessitating improved energy efficiency. Retrofitting residential buildings is key for sustainable urban development. In the UK, natural gas heating dominates household energy use and CO2 emissions. Changes in heating systems are essential for effective retrofits. LCSA helps identify optimal renovation options by integrating economic, environmental, and social sustainability. Despite increasing research on LCSA, studies focusing on heating system changes in residential retrofits are scarce. This study aims to fill this gap by evaluating electric heating system retrofit options in UK homes, using an LCSA approach to determine the optimal option from a comprehensive perspective.

Methodology: A case study was conducted on retrofitting heating system options for a semi-detached house in Bristol, UK. The study assessed (baseline) gas boilers, (i) electric boilers, (ii) air source heat pump (ASHP). LCC was applied to evaluate the economic impact of each option, considering initial investment, operating costs, and maintenance. LCA measured the environmental impact, following EN 15978 and using GWP as an indicator. Finally, S-LCA was applied, utilizing indicators such as job creation and labor conditions during the Retrofit stage, and adopting occupant-oriented indicators like occupants' health and comfort in the Use stage.

Results: ASHP showed the largest reduction in energy consumption, proving to be the minimal life cycle cost despite higher initial and maintenance costs. ASHP had the highest impact on embodied carbon but also led to the most significant reduction in operational carbon emissions, resulting in the lowest overall environmental load. S-LCA provided insights into job creation, labor conditions, and impacts on occupants health and comfort.

Conclusion: This study identified optimal retrofit options for electric heating systems. ASHP was the best option in terms of cost and environmental impact. S-LCA highlighted the impact of retrofit on social aspects and occupants' health and comfort, emphasizing sustainability on social dimension. These findings underscore that an integrated decision-making process covering comprehensive perspectives is essential for advancing sustainable residential retrofit. This research paves the way for future studies and practical implementations aimed at enhancing the overall sustainability of residential building.

2.01.P-Mo029 Environmental Payback of Concrete Due to Carbonation Over Centuries

Thomas Elliot, Aalborg University.

This research introduces a dynamic life cycle assessment (LCA) based carbonation impact calculator designed to enhance the environmental evaluation of cement-based construction products. The study emphasizes the limitations of static LCAs which fail to capture the progressive and time-dependent nature of carbon sequestration through carbonation. Utilizing dynamic LCA, we demonstrate how carbonation can substantially mitigate initial production emissions and adjust radiative forcing over long periods. Our scenario analyses illustrate the significant variability in carbonation effects, driven by environmental factors, cement composition, and the use of supplementary cementitious materials. Key findings indicate that carbonation not only reduces the carbon footprint of concrete by reabsorbing a portion of the CO2 released during cement calcination but also highlights the critical role of modeling choices in environmental impact assessments. The carbonation calculator developed in this study offers a sophisticated, yet user-friendly tool, providing both researchers and practitioners with the ability to dynamically model the sequestration potential of carbonated concrete, thereby promoting more sustainable construction practices.

2.01.P-Mo030 How to Address User-Behavior Uncertainty in the Life Cycle of Novel Systems? A Probabilistic Approach

Carla Rodrigues, University of Coimbra; Fausto Freire Fausto Freire, University of Coimbra.

The use phase is usually the main contributor to the life cycle impacts of product systems that highly depend on the user behavior, such as buildings, vehicles, HVAC (heating, ventilation, and air conditioning) systems, or toilet systems, which can be difficult to estimate the environmental impacts of the use phase due to the high uncertainty of the user preferences. Incorporating uncertainty is particularly important for the life cycle assessment of novel systems at the early stages of design (where the opportunities for improvement are higher) and when user-behavior uncertainty is relevant. The main objective of this article is to propose a probabilistic life cycle approach, which combines user-behavior scenario analysis, pairwise comparative analysis to communicate uncertain results, and global sensitivity analysis (using Spearman Rank Correlation Coefficient) to assess the most influential user-behavior input parameters (to the output variance). To demonstrate its effectiveness, this approach is applied to a novel toilet system for a comprehensive comparison with a conventional system (toilet and bidet). A combination of discrete (alternative usage patterns) and stochastic scenarios (resulting from the combination of uncertain input parameters, such as time of use, water flow, number and type of toilet paper sheets, water temperature, etc.) are evaluated to understand the influence of user decisions on the results. The pairwise comparison indicator analysis shows that the novel toilet system has significantly lower environmental impacts than the conventional system in all categories except for marine eutrophication. Global sensitivity analysis results show that the input parameters related to toilet paper (conventional system) and washlet (a self-cleaning system in the novel system) have the largest influence on the impacts. This article highlights that novel product systems, highly dependent on user preferences, can reduce impacts compared to conventional systems and sheds light on how user behavior becomes less influential as product systems are designed to be more efficient.

2.01.P-Mo031 Towards More Accurate Life Cycle Assessment Result Using Nigeria Ecological Scarcity Method

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1. Background and purpose

Rapid population growth and economic activities are projected to increase energy consumption and associated greenhouse gas in developing and emerging economies like Nigeria. Nigeria, as the fifth largest producer of palm oil globally and the largest consumer in Africa, has been rapidly developing its agriculture/bioenergy industry owing to strong government commitment. While the sector plays an important role in meeting the rising energy demand and offers a greener and better alternative to fossil fuels, its environmental impacts need to be properly assessed.

In Switzerland, the Ecological Scarcity Method was used as the policy decision tool for developing the Biofuels Life Cycle Assessment Ordinance (BLCAO) and other biofuels. Although the Eco Factors developed in Switzerland and other countries can be applied in carrying out LCA analysis of biofuels and alternative energy sources in Nigeria, they will not reflect the environmental realities of Nigeria.

Therefore, the objective of this study is to adopt the "distance-to-target" Ecological Scarcity Method (ESM) to develop Nigeria's eco-factors, empowering us to assess the impacts of palm oil production accurately.

2. Methods
The method applied to Nigeria is based on the mathematical formula of the ESM developed and applied in Switzerland (FOEN, 2021). The latest version of the method (FOEN, 2021) was used. The ESM uses transparent, usually government-defined policy, environmental quality targets as its benchmark for determining eco-factors.

The developed is used to carry out an LCA of palm oil production of small-scale, semi-mechanised and large-scale mills across four impact categories; freshwater consumption, energy resources (renewable and non-renewable), greenhouse gas and emissions to air (NOx, NMVOC, SO2and PM2.5). The system boundary for the production is a gate-to-gate approach and it includes the processing of fresh fruit bunch from when it was received at the factory gate to when the palm oil is produced. Finally, the comparative LCA is conducted using Switzerland, Japan, Thailand, and the European Union Eco Factors.

The life cycle inventory and background data were gathered from the work of Anyaoha and Zhang (2023) and Ohimain and Izah (2014, 2015). In this study, GHGs and other air pollutants due to the burning of biomass are not considered as they are of biogenic origin.

3. Results
The analysis indicates that the Eco Factors are 0.8, 0.85, 0.91, 4.13, 1, 17, 16, and 3 Nigeria Eco Point per m3, MJ NRE-eq, MJ RE-eq, g CO2e, g NOx, g NMVOC, g SO2e and g PM2.5 in respective units. The Eco Factors were used for the life cycle assessment of palm oil and the results indicate that semi-mechanised mills have higher environmental impacts than the smallholder and large-scale mills. Greenhouse gas from the combustion of fossil fuels used in the operation of the mills appears to be the main cause of the impacts and emissions to the environment.

The results of the comparative analysis show that the EU, Japan, and Switzerland have the lowest impact scores across the three different mills. For Thailand, the impact of semi-mechanized and large-scale mills is similar. Overall, the results show similar trends to that of Nigeria where semi-mechanized and small-scale mills had more impact while the impact from large-scale mills was lower.

4. Conclusions
This study develops an LCIA method for Nigeria using the Swiss "distance-to-target" Ecological Scarcity Method. The Eco Factors were used to assess the impacts of palm oil in Nigeria. The study revealed that small-scale and semi-mechanised mills and GHGs is the critical hotspot in the palm oil value chain. The source of the GHGS is from fossil fuel consumption used to power the mills and pump water. Our results highlight the need to integrate renewable energy sources.

2.01.P-Mo032 Footprint Cohesion and Prevalence of Environmental Impact Categories in Blue Mussel Aquaculture Life Cycle Assessments

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Background and Purpose: Low trophic aquaculture is frequently associated with a low environmental footprint compared to alternative food products. The challenges are however that most studies are performed either on few impact categories simultaneously or using rudimentary input data. A review study of the various environmental footprints of blue mussel aquaculture was conducted to evaluate the impact categories used, and the cohesion of the concluding values.

Methods: A literature review was conducted using the Clarivate Web of Science. The search strings were sorted into environmental impact, blue mussel species, and production methods, before they were compiled. The most prevalent studies found, focused either solely on blue mussels, environmental footprints, or had not conducted an independent LCA. But only articles including all aspired search terms were included in the review.

Results: Blue mussel aquaculture was found to be most frequently assessed for its global warming potential, eutrophication potential and acidification potential. In total, more than three quarters of the analyses evaluated these impact categories and showed standard deviation close to the average. Impact categories such as depletion of abiotic resources (minerals/fossil) and ozone, human toxicity potential, photochemical ozone formation, water use, marine ecotoxicity, and cumulative energy demand were less frequently analysed. This consequently results in larger gaps in the findings, with a range between the highest and lowest estimates, differing by a factor of a thousand in several impact categories. The least common impact categories were also identified like terrestrial eutrophication, particulate matter, ozone formation (human health), non-cancer human toxicity, marine eutrophication, land-use and ionizing radiation. These are also valuable categories to be aware of, though the lack of analysis performed on them makes their results less comparable and difficult to distinguish the values from their independent LCA's. Alongside, many of the evaluated studies highlighted the need to assess the aquaculture practices impact on the local biodiversity, though currently, no studies have evaluated this within traditional LCA.

Conclusions: The review provided a thorough evaluation of the impact categories frequently assessed in blue mussel aquaculture, highlighting areas with insufficient data or discrepancies. Lastly, the study showcases the impact of how studies are handling environmental benefits differently, and how it leads to major differences.

2.02 - Chemical Footprint: Informed Decision Making for Reduced Chemical Risks

2.02.T-01 Making Chemical Footprints Practical: User Needs and Drivers

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Background and purpose
Hazardous chemicals are released throughout the life cycle of products and services, harming humans and the environment. Chemical footprint calculation can empower industry actors to take actions to reduce potential impacts from hazardous chemicals related to their product portfolio. Herein we provide an overview of the available tools for chemical footprint calculation and their strengths and limitations.

Methods
Our mapping was based on identification of existing tools that without further adaptations can be used to calculate chemical footprints, based on available summary literature and previous experience by the authors.

The tools are currently being tested in a number of case studies with industry partners. Through this work user requirements are observed and related to the user and the decision context.

Results
We identified 12 life cycle inventory (LCI) data repositories. All LCI databases contained flows relevant for chemical footprinting but no database had this explicit scope, and hence we concluded that all are likely to contain data gaps.

We identified 15 life cycle impact assessment models covering toxicity indicators in current use. No one model covers all possible impact pathways for ecotoxicity and human toxicity pressure from products and services. Interrelationships were observed between the models where both model structures and related databases have cross fertilized development.

Several drivers to calculate chemical footprints were identified, e.g. multiple policies under the European Green Deal.

Via case studies we are currently building an understanding of industry actor requirements on tools for chemical footprinting.

Conclusions
While several tools for chemical footprinting are available, there is still a need for tool development to make possible the practical implementation of complete footprinting, covering all relevant exposure pathways. Policy drivers are already in place and are expected to keep building requirements for the inclusion of a life cycle perspective also for chemical safety issues. Whether the future of chemical footprinting lies within the current chemical safety sphere as regulated under e.g. the Regulation on the Registration, Evaluation, Authorisation and Restriction of Chemicals, or within the sustainable product sphere, as regulated under e.g. the Ecodesign for Sustainable Products Regulation, or both, is not yet clear.

2.02.T-02 Risks and Impacts of Chemicals in Consumer Products on Human Health and Ecosystems: Extending USEtox Coverage
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The ubiquitous presence of more than 100,000 chemicals in thousands of consumer products used on a daily basis stresses the need for screening a broader set of chemicals In order to facilitate and extend LCA practices the USEtox model was extended to enable user to calculate characterization factors for human and ecotoxicity exposure to chemicals during product use.
To cover a wide range of chemicals-products combinations, we developed six complementary model to facilitate its usage for: a) the object interior model – for chemicals in toys, building materials and dried paints, b) the food contact model - for chemicals in food and beverage packaging, c) the object surface model – for cleaning and home maintenance products and fresh paints, d) The skin surface layer – for personal care and other skin applied products, e) the near-person, indoor and outdoor air, as well as water and soil compartmental models, for direct emissions in the indoor or outdoor environment. Substance coverage was substantially extended t from less than 750 regulatory chemicals to experimentally derived data for more than 8000 chemicals for ingestion and more than 2000 for inhalation. Using random forest algorithm enabled us to obtain effect data for more than 34000 chemicals. Freshwater ecotoxicity data were derived for more than 9’000 chemical.
We developed mass balance models for both water- and solvent-based paints, predicting emissions during wet and dry phases and screened exposures and risks for 65 organic chemicals in water-based and 26 in solvent-based paints, considering 12 solvents. Chemicals of concerns (CoCs) were identified. Water-based paints generally pose lower health risks than solvent-based paints but might contain biocides of high concern. USEtox 3 enables us to screen more than 9350 chemical and 20 products or environmental compartments, for a total of more than 600,000 CFs. This approach consistently operationalizes the inclusion of chemicals in products during use for LCA and shows that these exposures are substantial and in most cases higher than the impacts of toxics over the rest of the life cycle.

2.02.T-03 Adding up the Additives: Data Availability and Needs to Enable Robust LCAs of Plastics
Heather Logan, Technical University of Denmark; Steven DeMeester, Ghent University; Anders Damgaard, Technical University of Denmark.

Adding up the Additives: Data Availability and Needs to Enable Robust LCAs of Plastics

Additives are essential to the production and function of plastics, yet they are, like many chemicals, underestimated, understudied, and underestimated in the Life Cycle Assessment (LCA) of plastic products. Additives significantly contribute to the entropy of plastic recycling, making an ever-growing source of materials even more complicated. In fact, recent investigations have found that 17,000 chemicals, more than 43,000 chemical abstract service registry numbers (CASRNs), are used in plastics and in need of better risk and reporting data. With scrutiny increasing into the use of these materials, it will be essential that LCA practitioners account for and incorporate additives into their LCAs of plastics. However, the question arises: how many of these chemicals are available in LCA databases today, what functions and plastics can they be applied to, and where should database developers and practitioners target data development to best meet the coming demands for incorporating additives into their LCAs of plastics? In this study, we have combined state-of-the-art knowledge from both the UNEP (2023) and PlastChem (2024) to the offerings from three of the leading database providers for LCA background data: Ecoinvent, LCA for Experts (formerly GaBi), and CarbonMinds.

Using reported CAS RNs, we compare the numbers reported in both PlastChem (2024) and UNEP (2023) to the CAS RNs provided with the database offerings for Ecoinvent v3.9.1, v 3.10, Lca for Experts (GaBi) 2023, and CarbonMinds 2022. This allows us to identify which additives are available as activity datasets and where data gaps exist in activity datasets available to practitioners today. We then match each of these activity datasets to knowledge about current regulation, reporting, and usage data from the PlastChem database (2024) database and the UNEP report (2023). The outcomes of this work are summarized in an easy-to-use tool that lets practitioners see what additive data is available in their chosen database for a given polymer, use case, and additive function.

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science on plastic chemicals - Identifying and addressing chemicals and polymers of concern.

2.02.T-04 Substitution of (Cyclic) Siloxanes in Cosmetics, a Case Study to Apply Life Cycle-Based Chemicals Assessment Tools with-in the Safe and Sustainable-by-Design Framework

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Background

A substitution process for chemical substances in products requires guidance for both safety and sustainability, which the MISTRA SafeChem programme addresses by applying a novel combination of life cycle-based chemicals assessment tools aligned with the recommendations of the new safe and sustainable-by-design (SSbD) framework. Results provided further insights to characterize the chemical footprint and were assessed along with other life cycle impacts accounting for the production of the chemicals.

Materials and methods

The workflow that was developed in the programme and applied for a case study includes four steps; 1 Prioritization of alternatives by consideration of function and by means of a hazards assessment; 2 Estimation of direct toxicity potential during the production process of the chemicals using ProScale ; 3 Prediction of direct exposure risk and indirect impacts on the general population and freshwater ecosystems for the application phase using the USEtox 3.0 near-field/far-field model; 4 Complementary environmenal sustainability assessment adding cradle to gate information for an LCA (including chemical footprint impact categories).

Results

Preliminary results showed advantages for the alternatives from a sustainability point of view, while only one out of three alternatives showed lower exposure risks compared to the siloxane; due to the preliminary nature, this is suggested as a starting point for further evaluation. Models are under development and subject to change, a fully integrated cradle to gate assessment of a multitude of impacts is not yet possible. The models and tools create new quantitative estimates of direct exposure risk during different life cycle stages, in this case for use phase and production; further addition of downstream processes for handling waste and wastewater is not yet included.

Conclusions

Applying a comprehensive and consistent framework is currently hampered by a lack of data for inventory and impact assessment. However, a general intent to avoid trade-offs between safety for users and environmental impacts requires a holistic perspective. Our workflow and combination of lifecycle-based chemical assessment tools can contribute to an improved understanding of the chemical footprint and other life cycle impacts in chemical substitution cases to find better alternatives.

2.02.T-05 On the Applicability of Incorporating Bioassays in Life Cycle Assessment for More Complete Evaluation of Advanced Wastewater Treatment

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Background: Removal of micropollutants by advanced wastewater treatment (AWT), such as ozonation (O3) or activated carbon (AC), has been a hot topic in recent decades, culminating in the coming update of the European wastewater directive. Stricter effluent requirements are expected, including removal of micropollutants, as well as the demand to mitigate climate impact. To navigate the trade-offs between these aims life cycle assessment (LCA) is a commonly utilised tool.
Most LCAs on AWT use chemical analysis and report greater toxicity impact than toxicity benefit of removing micropollutants. Recently, a new method to also include bioassay results in LCA by using reference substances was developed. Here, we aim to evaluate the applicability of this method through a case study comparing two different AWT.
Method: A planned, medium-sized (45000 population equivalents) wastewater treatment plant (WWTP) will include a facility for AWT with O3. Moving bed biofilm reactor (MBBR) or granulated AC (GAC) is suggested for post-treatment. An LCA comparing O3–MBBR to O3–GAC using bioassays is attempted. Monitoring of status at current WWTP and recipient has previously been made using chemical analysis and in vitro bioassays. Bioassay results are compared with dose-response curves of reference substances thus obtaining the biological equivalent concentrations.
Results: Taking the example of the estrogenic hormone ethinylestradiol (E2), bioassay results on current WWTP effluent showed 40 times larger E2-eq. concentration than suggested by chemical analysis indicating the importance of sensitive analytical methods. After AWT, most of the estrogenicity was removed, corresponding to a reduction of freshwater ecotoxicity potential (FETP) of 0.026 CTUe/m3 wastewater. This value can be compared with the preliminary estimation of FETP from construction and operation of the O3 facility of approximately 0.10 CTUe/m3 wastewater. These early calculations indicate that AWT benefits seem higher when utilising bioassay results than chemical analysis data.
Conclusions: Making a calculation and comparison between the two options was possible using the inclusion of bioassay results in LCA. However, data availability needs to be addressed. When using LCA in a prospective way, there is a lack of specific data. In the long run, it would be interesting to use this method for assessing which WWTPs that would significantly benefit from the implementation of AWT.

2.02.P - Chemical Footprint: Informed Decision Making for Reduced Chemical Risks

2.02.P-We013 Life Cycle Based Risk and Opportunity Mapping, Identifying Pathways and Dead Ends in Early Innovation

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Background and Purpose
Life cycle-based risk and opportunity mappings (LCBROM) can analyse concerns for new material or process hindering further development and/or upscale in future. The LCBROM also aims to find the major advantages over state-of-the-art benchmark

technologies. This qualitative screening approach is used to investigate potential risk and opportunities as “red flags” and “critical hot spots” of new material/process developments by considering all life cycle stages (production, use-phase, and disposal). This is done with the help of a systematic MET matrix that summarizes risks of Materials use, Energy consumption and Toxicity issues of each life cycle stage[1].

Methods
The LCBROM method is performed in the following steps:
1. Initial litterature reseach.
2. Distributing initial questionnaire to technology provider.
3. Meetings with technology provider and second questionnaire to fill in MET matrix.
4. Summary of information in reports.
5. Reflection and adaptation of method.

Results
• A formalised stepwise approach and defined input information facilitates the execution of the method.
• Involving all stakeholders is important, to get access to accurate information and answers to the questions asked.
• In the process participating stakeholders become aware of the benefits of applying a life cycle perspective to their material or technology and become more observant with regard to the possible environmental impact of the product.

Conclusion

LCBROM is a useful screening method concidering an entire life cycle in early stages and has been successfully applied to materials and technologies for air and water treatment in early innovation stage in the MISTRA TerraClean project. The LCBROM could also be used as an early-stage methodology in evaluations according to the Safe and sustainable by design (SSbD) framework outlined by JRC [2].

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2.02.P-We014 Ecotoxicity Impacts of Pesticide Use in Finnish Field Vegetable Crops in 2003-2019

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The use of chemical pesticides differs between crops and years, and they might negatively affect the surrounding environment, its organisms, and humans. However, comprehensive information on the use of chemical pesticides on different crops and their related environmental impacts is currently lacking.

We studied the potential freshwater ecotoxic impacts of 57 pesticides used on carrot, potato, swede and fresh pea in Finland in 2003-2019 using a method based on the scientific consensus model USEtox. The PestLCI Consensus model was used to estimate pesticide emission fractions into the environment. The longitudinal data (17 years) covered the use of pesticides of more than 100 field vegetable farms in the years 2003–2019 in South-western Finland.

The highest ecotoxicity impacts were found for carrot (36% from all pesticides used in all crops) and the second highest were for potato (31%). Pesticides used in swede contributed with 24% to the total impacts, and the smallest impacts were found for fresh pea (9%). Herbicides (21%) in carrot accounted for most of the impacts from all pesticides on all crops, and fungicides used in potato (20%), and insecticides in swede (19%) accounted for nearly the same amount of impacts. Fungicides in fresh pea had the lowest impacts (0.2% of total considered impact). When the cultivated area was taken into consideration, the order for the impact results between crops changed. The highest impacts were then found for fresh pea and the smallest for swede, because of the largest and smallest cultivated area, respectively, compared to other considered crops.

Single substances had a significant impact on the total ecotoxicity impacts. The most hazardous substances were herbicides aclonifen and linuron (not used after 2013), and insecticide lambda-cyhalothrin on carrot, fungicide mancozeb and herbicide aclonifen in potato, insecticides lambda-cyhalothrin, cypermethrin, and dimethoate (not used since 2018) in swede, herbicide aclonifen and insecticide lambda-cyhalothrin and alpha-cypermethrin in fresh pea.

Our results provide a long, quantitative window on the impacts of pesticides in field vegetables in southwestern Finland. Using this method, the environmental impacts of individual hazardous pesticides can be identified and ranked. The results show that environmental impacts of pesticides can be decreased by looking for suitable alternatives for the most harmful substances and developing pest control in a more sustainable direction.

2.02.P-We015 Decreased Ecotoxicity Impacts of Sun Care Products With Laccase-Based Solutions

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Background and purpose: Sun care products used for UV protection include several chemicals that can have detrimental impacts on the aquatic ecosystems when released to the natural waters in the use stage. These chemicals include, for example, oxybenzone, octinoxate, benzophenones and titanium or zinc oxides. An alternative approach is to substitute such chemicals with safer biobased compounds. One of the innovations in the EU-project OXIPRO deals with validating laccase-based production of melanin-like polymers for sun care product formulation, which would enable decreased use of these above-mentioned chemicals and thus minimize the ecotoxic impacts from the use of sun care products.

Methods: The environmental impacts of traditional sunscreen lotion were studied with life cycle assessment (LCA) method (ISO 14040) and compared to the estimated composition of the new sunscreen with the laccase-derived ingredient. The UV-filter functionality of both products is considered similar in the functional unit. Both life cycles are modelled as cradle to grave system boundary, including the use stage where the ingredients of the sunscreen are expected to be released to natural waters either in the use stage (via swimming) or after use when the consumers are washing themselves. The environmental impacts are studied with the Environmental Footprint 3.1 (EF3.1) impact assessment method suggested by the European Commission.

Results: Since the new sunscreen composition is still in the development phase, the study shows the estimated possibilities of the solution by pinpointing the biggest potentials by providing information for the sunscreen producers regarding the ecotoxicity of the traditional chemicals.

Conclusions: To claim UV properties of a cosmetic product within EU, specific chemicals are mandated by legislation. Therefore, while an alternative laccase-based formula does not eliminate the need for traditional UV filters, its goal is to reduce their global consumption by at least 5-10%. The extent of the decrease in ecotoxicity impact depends significantly on the UV filter chemical being substituted and if the sunscreen is discharged to a fresh or sea water body.

2.02.P-We016 Life Cycle Impact Assessment of Metals in Mine Tailings

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Current estimates of long-term metals release from tailings dominate life cycle impact assessment of metals and are not reliable for regulatory use. There is a lack of understanding of the underlying data behind existing life cycle inventories (LCI). In this work, we take a wholistic approach to understanding the problem, including consideration of tailings site information, metal geochemistry, and how these information can be incorporated into LCIA.

For improvements to be made, a multi-faceted approach is needed, particularly in five areas: compliance with LCA standard practice; mass-balancing; consideration of tailings as a resource; more site-specific data & models; and consistent timeframe across goals, scope, LCI Models and LCIA Methods. Improved LCI models should be as simple as possible and as complex as necessary.

To address the area of 'models used to develop the LCI', we propose a simplified, yet sensitive conceptual model. This includes factors most influencing releases from tailings including the regional setting (like climate, hydrogeologic setting, and ore geology); processes used to produce, manage & store tailings; water Balance (for the given processes in the given regional setting); and the ceochemical processes that therefore take place.

This work will help develop a workable number of archetypical scenarios (combinations of climate, ore, and process categories) that could form the basis of a new set of LCI Models to estimate releases from tailings facilities over different timeframes.

2.02.P-We017 Comparative Life Cycle Assessment of Photocatalytic Flow Reactors for Solar-Driven Processes to Obtain Sustainable Long-Chain Alcohol-Based Fuels

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NEFERTITI is a H2020 Project aiming to develop solar-driven processes through a high-efficiency photocatalytic system that allows simultaneous conversion of CO_2 and H_2O into solar fuels such as ethanol and alcohols with longer chains (as isopropanol). This system provides an innovative alternative for transforming CO_2 into valuable products for the energy and transportation sectors.

The project integrates new heterogeneous catalysts, such as covalent organic structures and metal oxides combined with nanoparticles, along with luminescent solar concentrators, in two photocatalytic flow reactors powered by solar energy.

Following the Safe and Sustainable by Design principles (SSbD), the University of Burgos (ICCRAM) will evaluate the safety and sustainability performance of the different catalysts under development. To assess the environmental performance, the Life Cycle Assessment methodology will allow to identify hotspots and support decision making in early stages of the innovation.

This study presents a comprehensive LCA analysis of the two alternatives for the luminescent solar concentrators and the two photocatalysts developed in the NEFERTITI project for the first photocatalytic flow reactor (PCFR1) and a LCA assessment for the catalyst developed for the second photocatalytic reactor (PCFR2).

For the photocatalysts involved in PCFR1 processes, the environmental assessment shows a negligible difference (just 0.2% increment between COF system and C_3N_4 system), whereas there is 47% increase on the cost comparing C_3N_4 to COF system. Since all the materials for the PCFR1 are sourced from a single country, Ireland, comparative analysis of the social aspects cannot be conducted. Therefore, if the functionality of both materials is considered similar, the C_3N_4 based photocatalyst would be ranked first in preference, thus supporting the decision making for the technology development.

By integrating SSbD principles and conducting a thorough LCA and economic analyses, this study highlights the importance of sustainability considerations in the development of photocatalytic flow reactors for solar-driven processes. The findings contribute to the advancement of sustainable chemical processes and provide valuable insights for future research and development in this field.

2.02.P-We018 A Life Cycle Based Assessment Toolbox to Assess and Improve Safety and Sustainability of Chemicals – Half Time Report

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We describe the developments of the life cycle based tools in the Mistra SafeChem toolbox. Their application, and integrated use with hazard and exposure screening tools. The vision of Mistra SafeChem “is to enable and promote the expansion of a safe, sustainable and green chemical industry” and the toolbox is a key deliverable towards this vision. With another four years of research just granted for the programme to continue and further advance science and tool development, we herein give a half time report.

We defined the toolbox on life cycle based assessment as having three entry points: chemical alternatives assessment and chemical substitution with life cycle considerations, “chemical footprint assessment” (CFA), i.e. focus on (eco)toxicity life cycle assessment (LCA) impact categories, and broader scope LCA, integrating the CFA and additional impact categories. USEtox (www.usetox.org) and ProScale (www.proscale.org), for (eco)toxicity life cycle impact assessment (LCIA), are key tools in the toolbox.

The developments of the life cycle based tools included further advancements of USEtox and ProScale and the investigation of opportunities for digitalizing (eco)toxicity assessment in LCIA. By mapping the potential of machine learning based approaches, it was demonstrated that currently crucial data gaps can be filled for up to 46% of globally marketed chemicals. We further explored the aligned application of the toolboxes for hazard and exposure screening with the LCIA tools in dedicated case studies.

We conclude that a sustainable transition requires system thinking and integration of a full life cycle perspective. Novel tools for rapid screening and integration of hazard and risk information into LCIA are key for relevant decision support in process design and substitution. Tools like USEtox and ProScale, integrated with in silico approaches for substance property predictions, make this possible.

There is still room for improvement of the life cycle based tools in the toolbox; hence, for the coming four-year period, we look forward to address further challenges, including prospective assessment, further operationalization of tools for integrated assessment of safety and sustainability in an EU context, as well as substance specific challenges.

2.02.P-We019 SSbD in Practise: Environmental, Economic and Social Pre-assessment for Early-Stage Decision Making

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Metallization of plastics emerged 50 years ago combining the benefits of processing, lightweight and cost of plastics, together with the durability, tribological and anticorrosion properties of metals. However, the traditional processing to obtain the metallization of polymers involves both, highly toxic substances (Cr 6) and also critical raw materials (Paladium). The concern about these substances is leading the research towards greener alternatives for plastics metallization.

FreeMe Project supports the development of two novel technologies, not yet systematically tested from the safety and sustainability perspective. FreeMe aims to couple the research and development of these technologies with an iterative safety and sustainability. This approach will support the identification of hotspots and criticalities and elaborating recommendations for improvement before the processes evolves in the TRL, avoiding further costs and research efforts.

The application of the Safe and Sustainable by Design Framework (SSbD) has proved to be a powerful tool to identify the most critical aspects of the novel technologies. The SSbD strategy has been temporalized for its application in this Project, advancing in parallel to the technical research. The first assessment (Step 1. Intrinsic properties) was carried out through the identification in the ECHA system of the compounds used in the novel and classical technologies. Step 1 can be addressed at very early stages of the development (TRL 2-3), providing guidance for the selection of the compounds.

Even though it is not foreseen in the SSbD framework, it was found useful to develop a sustainability pre-assessment. The environmental review was focused in the quantification of the impacts associated to the production of each of the substances under study, through literature and databases information (EcoInvent). Additionally, a literature review of the traditional technology, stablishing an environmental baseline.

From the economic perspective, the cost for the raw materials can be estimated from a literature and market, including environmental impact through a monetary valuation into the final cost. The materials and chemicals involved were also mapped to identify the main producers worldwide as well as the value chains and global trends associated to their production and commercialization. Social aspects are in this way pre-evaluated to identify the most reliable suppliers. This will support economic and social decision making at a very early stage incorporating the sustainability dimension at low TRLs.

2.03 - Biodiversity and Ecosystem Services: Paving the Way Forward Towards Their Quantification in LCA

2.03.T-01 Rethinking the Life Cycle Impact Assessment Framework to Foster the Consistent Inclusion of Potential Impacts on Ecosystem Services

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Background and Purpose: The integration of ecosystem services (ES) into decision-making is critical for limiting the erosion of their supply. Life cycle assessment (LCA) is a key tool for sustainable decision-making. Different approaches have been proposed to include ES in LCA including integrating them within the life cycle impact assessment (LCIA) phase. However, current propositions for including ES in LCIA are inconsistent and limited. To support the development of characterization models addressing potential impacts on ES, this research introduces a comprehensive conceptual framework to ensure a consistent inclusion of instrumental values in LCIA.

Methods: The revised LCIA framework provides a comprehensive visualisation of all potential impact mechanisms linking inventory flows to existing and new areas of protection (AoPs) : “Human health” and “Ecosystem Quality”, and “Ecosystems and resources services”. Building on the “cascade model,” the framework highlights the connections between ecosystem functions, ES potential, and ES flows.

Results: The framework encompasses impact mechanisms induced by various environmental interventions, such as substances emissions, land use changes, and resource dissipation. It addresses the consequences of the loss of ES flow, considering both adaptation strategies (with associated economic costs and the expansion of system boundaries) and non-adaptation (leading to a loss of natural capital and potential impacts on others AoPs). We propose combining these outcomes into a new AoP called “Ecosystems and resources services” to account for instrumental values. The framework includes other characterization models available in LCIA, which may impact Human health and Ecosystem Quality directly through changes in ecosystem functions, independently of a change of ES supply. The framework was validated by mapping each impact category of the IMPACTWorld+ method onto one or several of the proposed impact pathways.

Conclusion: This clarified framework, along with the refined terminology, paves the way for a consistent and comprehensive inclusion of instrumental values in LCIA.

2.03.T-02 Riverine Fish Biodiversity in Peril: The Effects of Global Water Consumption

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Human activities in the Anthropocene era have significantly increased global water demand fourfold, resulting in severe repercussions for freshwater ecosystems. This surge has led to an alarming 84% decline in the worldwide population of freshwater species. Despite covering only 0.01% of the Earth’s surface, freshwater ecosystems harbor an impressive 9.5% of globally recognized animal species. Persistent threats to these ecosystems include alterations in river discharge and modifications in flow patterns. Approximately 65% of global river discharge faces moderate to high levels of threat, yet biodiversity conservation efforts are hindered by limited data availability. Within the framework of life cycle assessment (LCA), ongoing efforts aim to evaluate biodiversity loss and ecosystem quality. Various methodologies have been developed to address factors such as land use changes, climate variability, environmental pollution, and water consumption. Notably, assessing environmental impacts on freshwater ecosystems due to water utilization involves techniques such as habitat simulation within the LCA framework. This study investigates the impact of water consumption on global riverine fish species by utilizing specialized characterization factors alongside detailed, spatially explicit inventory time series spanning from 2000 to 2016. Data on watershed-level water consumption is sourced from the WaterGAP 2.2d hydrological model. The objectives of this study are twofold: to assess the impact of human water consumption on global riverine fish using updated characterization factors, and to explore potential relationships between nutrient adequacy and biodiversity impact caused by water consumption in crops. By conducting this investigation, we aim to shed light on the consequences of human freshwater use on riverine fish species and pinpoint associated hotspots of species loss. Furthermore, this study underscores the necessity of sustainable resource management practices by emphasizing the delicate balance between crop nutrient adequacy, water use, and biodiversity impact.

2.03.T-03 Time-Integrated Approach Based On GLOBIO And LCA Endpoint Models To Evaluate The Life Cycle Impacts On Biodiversity

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There is a need to evaluate the impact of products, services and organisations beyond carbon footprint and midpoint life cycle assessment (LCA). Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) reports a ranking of main pressures on biodiversity: land and sea use change, climate change, pollution, direct exploitation of species and invasive species; with land use as the main driver of terrestrial & freshwater biodiversity loss. To evaluate the impact on biodiversity at different levels, a variety of models exist and are tested by different actors: endpoint LCA studies, based on Life Cycle Impact Assessment (LCIA) methods (Impact World+, LC-IMPACT, ReCiPe), and other biodiversity assessment models such as GLOBIO. Each model has its limits and might give contradictory results using different approaches and units. Product Biodiversity Footprint 1.0 was developed by I Care and Sayari and published in 2019 to assess the impact on biodiversity of products and services. Since then, companies across different sectors tested the approach. In parallel, I Care and Iceberg Datalab co-developed the Corporate Biodiversity Footprint to address biodiversity loss at the organisation and portfolio levels.

After several years of applying PBF and CBF and understanding the pros and cons of the different existing methodologies, I Care decided to launch a methodological update. The aim of this research is to propose a methodology that: 1) allows to calculate a single-score biodiversity footprint, 2) is based on the IPBES ranking of drivers as weighting factors at global scale, 3) follows a time-integrated approach, 4) builds on the strengths from GLOBIO (for land use) and LCIA models (for pollution pressures), and 5) is coherent throughout the different scales : from product to organisation.

The new Product / Corporate Biodiversity Footprint 2.0 includes pressure-impact relationships for land use (occupation and transformation), climate change, water use, and pollutions (freshwater eutrophication, terrestrial and freshwater acidification, and freshwater ecotoxicity). The results are expressed in mean species abundance (MSA) as loss of biodiversity-rich surface over a period (km2.MSA.yr.)

The PBF/CBF 2.0 underwent a fundamental methodological update linking GLOBIO and LCA models. In the current context of the growing need to assess the potential biodiversity loss, this approach can be tested at both product and organisation levels.

2.03.T-04 Impacts of Organic Olive Cultivation on Ecosystem Services: a Life Cycle Assessment Approach

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Background and Purpose:

The olive tree (Olea europaea L.) is a symbol of the Mediterranean, an integral part of its diet, culture and economy. Olive oil production is a key sector, especially in Italy, where it supports about 600,000 farmers, half of them in Puglia. Despite existing studies on the environmental performance of olive oil production, comprehensive research on its impact on ecosystem services is lacking. This study aims to assess the environmental impact of olive cultivation on water purification (WP), soil erosion control (SEC) and carbon sequestration (CS) ecosystem services using life cycle assessment (LCA) methodology.

Methods:
The study compared two olive farms in Apulia: one conventional (SC1), using mineral fertilizers, and one organic (SC2), without synthetic fertilizers. Using a cradle-to-gate approach and one hectare as the functional unit, data were collected through farmer surveys. The impacts of WP, SEC and CS were quantified using the RothC and InVest models, and characterization factors were calculated in line with the UNEP-SETAC guidelines and using data sets from the Copernicus Land Monitoring Service and the European Soil Data Centre.

Results:
The organic scenario (SC2) showed an 83% improvement in WP due to reduced and organic fertilizer use, minimizing nitrogen runoff. SEC impacts were similar for both scenarios, influenced more by agricultural practices such as tillage and grass margins than by fertilizer type. CS was 11% better in the organic scenario due to 32% more biomass residues from pruning left on the field.

Conclusions:
The study highlights the importance of specific agricultural practices and input types in environmental impacts on ecosystem services. It suggests expanding the environmental impact categories for a more comprehensive analysis. Future research will include other functional units, such as yield and quality, and additional indicators and production sites to better understand the impacts of organic versus conventional olive production in the Mediterranean.

2.03.T-05 A Life Cycle and Ecosystem-Based Approach to Assess the Environmental Sustainability of Multi-Use Offshore Farms

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Background and purpose
The Belgian part of the North Sea (BPNS) is one of the busiest in the world, with multiple human activities taking place, from transportation, fishing, offshore wind energy production among others. This can lead to a competitive environment and a limited use of marine space. To regulate the use of marine space, Belgium implemented a Marine Spatial Plan (MSP) for the period 2020-2026. This MSP encourages the co-location of Blue Economy activities, for example offshore wind energy production and aquaculture of mussels or seaweed. Multi-use offshore farms (MUOFs) have the potential to address marine space limitations and stimulate collaborations and new economic opportunities. However, the local (e.g. marine ecosystem services) and global environmental (e.g. climate change) impacts, both positive and negative, along the value chain of these combined activities are not yet well understood. This study aims to comprehensively quantify the potential impacts of a MUOF in the BNPS employing a life cycle and ecosystem-based approach.

Methods
The methodology was applied to an existent offshore wind farm co-located with a designed mussel farm, with its functional being a basket products, i.e. yearly average electricity and mussel production. Local impacts on marine ecosystem services (ESs) are evaluated using different models and indicators, while adopting a more generic approach to quantify the impacts on terrestrial ESs and global impacts. Extensive data, including technological, biophysical, physico-chemical and monetary, was collected. Results were aggregated into a monetized single value, distinguishing between handprint (benefits) and footprint (burdens).

Results
Findings indicate that positive impacts exceed negative ones by a factor of 14, largely driven by the handprint of the local provisioning ecosystem service ‘offshore renewable energy.’ Most of the MUOF’s footprint is attributed to the supply chain of primary and secondary materials to manufacture its components.

Conclusions
This study contributes to have a better understanding of the multi-scale burdens and benefits of MUOFs, and exemplifies the application of a life cycle and ecosystem-based methodology to assess the environmental sustainability of human activities. The insights provided can serve as a valuable tool in supporting science-based solutions for global challenges and contributing to well-informed decision-making processes.

2.03.P - Biodiversity and Ecosystem Services: Paving the Way Forward Towards Their Quantification in LCA

2.03.P-Tu009 Life Cycle Assessment Based Modelling of Welsh Timber Product Systems Incorporating Ecosystem Services Impacts

Thomas Henderson, Bangor University; Ashley Hardaker, Bangor University; John Healey, Bangor University.

Background and Purpose
Reducing the UK’s 80% dependency on imported timber requires expansion of the commercial woodland resource. In Wales, the management of new forests needs to minimise negative environmental impacts and maximise societal benefit. Timber production and processing have very different environmental burdens and impacts on ecosystem services depending on where the forest is located and what value chain the timber enters. Currently, political and scientific discourse often overlooks the spatially and temporally explicit life-cycle ecosystem services impacts and environmental burdens of timber product systems, considering both the ecological aspects of the production stage and the technological aspects of processing and value chain stages simultaneously.

Methods
Drawing from literature on integration of the ecosystem services cascade framework into life cycle assessment, this project involves the soft coupling of ecosystem services modelling software and life cycle assessment (LCA) methods. Various afforestation and management scenarios are explored, utilizing detailed, spatially explicit species growth and yield models within an identified opportunity space for woodland creation in Wales. Within each scenario, assessments of several individual ecosystem services within the temporal system boundary are generated using ecosystem services modelling tools. They are aggregated with the damage to ecosystem services from later value chain processes, generated using

site generic characterisation factors for impacts on ecosystem services.

Results
Net ecosystem services impacts are visually represented using geographical information systems, showing the spatial heterogeneity within the option space for each scenario, alongside the environmental burdens of processing.

Conclusions
This advancement in the emerging discipline of ecosystem services assessment in LCA broadens the scope of previous literature out to allowing representation of potential gains in ecosystem services at the landscape scale, while retaining the advantages of the clear communicating of impacts of standard LCA. The projects aim, to demonstrate how different locations and management of new commercial forests and associated value chain processes and product breakouts impact ecosystem service delivery in Wales, is with a view to informing currently developing policies for the strategic expansion of the Welsh timber resource.

2.03.P-Tu010 A Food Biodiversity Database – Meal Service Case Study

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Background and Purpose
The link between climate impact and food production is well established. The connection between food and other environmental impacts is less explored, especially biodiversity impacts. To fill this gap, Research Institutes of Sweden (RISE) has developed a database which features the biodiversity footprint of food items. The focus is on products consumed in Sweden, which includes food produced in Sweden but also imported food, ingredients and feed.

To evaluate the applicability of the database, connection to reality is needed, which the meal service company Compass Group AB represents. This paper will present findings from the case study with the company.

Methods
There are several methods to assess the biodiversity impact of food production and consumption that can be implemented within existing LCA-frameworks, on midpoint or endpoint level. Midpoint impact assessments are often based on the land use (area and intensity) in combination with parameters linked to orgin of production, in our database we use the midpoint method described in Chaudhary & Brooks in 2018. The database was applied on a selection of Compass Group's procurement of food. Biodiversity footprints were calculated for each food item, the results were analyzed, identifying hotspots and tracking back to background data to find explanations.

Results
The impacts from Compass Group's procurement for one year will be presented, including high/low-impact commodities and the influence of country of origin. Challenges will be presented, where the most time consuming task was to assign the food items the correct biodiversity footprint, which is based on the food item, its country of origin and production method. Several challenges arose, linked to data structure, lack of information on the procured food items, or lack of production data on the food items.

Conclusions
The outcomes from the case study will guide the future development and expansion of the database. The database enables inclusion of an additiona impact category which we expect to be of valuable use for decision making and target-setting in e.g. retail, wholesale, restaurants, public kitchens, and the food production industry.

Future case studies can include applying the database as support in procurement and decision making, using the data in communication, and doing so to further evaluate how applicable the database is and how it can support procurement and strategically planning of meals.

2.03.P-Tu011 Quantitative Assessment of Forest Fires in LCAs of Extensive Livestock Grazing Systems

Montserrat Nunez, Institute of Agrifood Research and Technology (IRTA); Miquel Andón, Institute of Agrifood Research and Technology.

Extensive livestock grazing in forest areas can be used as a tool for landscape modelling and reducing the risk (frequency) and impact (severity) of wildfires. Extensive farms in forest areas are multifunctional, providing, among others, the ecosystem service (ES) of fire regulation in addition to the provision of food (meat and milk). However, Life Cycle Assessment (LCA) studies typically only include the provision of food, which is detrimental for extensive systems when compared to intensive systems due to their lower food productivity. In this LCA of two extensive beef cattle farms in Spain, we have quantified the benefit of extensive livestock grazing by combining two aspects: 1) quantifying the role of animal grazing in the reduction of emissions from the burning of biomass in a potential forest fire; 2) Including the compensatory payments to the farmer for the management of the understory. The environmental burdens were then distributed between the two considered farm functions (i.e., fire regulation and food) using economic allocation. To quantify the role of animal grazing in the reduction of emissions from the burning of biomass (aspect 1 cited above) we: i) calculated the existing biomass in the different vegetative strata (herbaceous, shrubs, trees); ii) calculated the biomass consumed or disturbed during grazing; iii) the remaining biomass is available to burn in a fire. The results showed: 1) a reduction in emissions from fires and associated impacts of 1-5% in the affected categories (climate change, photo-chemicals, particulate matter, carcinogenic pollutants, acidification, freshwater eutrophication); 2) A drastic reduction of around 40% of the burdens associated with the provision of meat, which are now allocated to the fire regulation ES. These methodological adjustments make it possible to include the multifunctionality of extensive systems and generate a fairer basis for comparison between intensive systems, which only fulfil the function of providing food, and extensive systems, which are multifunctional. Communication should be based on ES corrected results to avoid unfair comparisons between farming intensities. Future work will focus on developing an LCA indicator to capture the potential benefit of silvopastoralism in reducing the frequency of fires, and not only through reduction in emissions in the conventional categories as done here.

2.03.P-Tu012 Biodiversity Efficiency vs. Effectiveness at the Product Level

Jan Paul Lindner, University of Augsburg; Horst Fehrenbach, Institute for Energy and Environmental Research (ifeu); Peter Koch, Ecolysis GmbH; Silvana Bürck, Institute for Energy and Environmental Research (ifeu); Nico Mumm, University of Augsburg; Julian Quandt, University of Augsburg; Quandt.

LCA addresses a broad variety of environmental issues quite well, e.g. climate change, abiotic resources or air quality, but biodiversity is still an open topic. We have developed an add-on methodology for including biodiversity in LCA and calculated impacts for close to

2,700 food products from the French Agribalyse database. The list includes many products in organic and conventional varieties, and these comparisons are of particular interest both from a philosophical and a political perspective. Organic agricultural practices may be more benign than conventional (more effective in terms of avoiding impact), but the lower yield can raise the impact per product unit significantly (less efficient). In this presentation, we show selected organic vs. conventional comparisons of food products and highlight the drivers that tip the comparison in either direction. We also discuss how the methodology can be engineered to reflect preferences in the efficiency vs. effectiveness debate.

2.03.P-Tu014 Analyzing the Importance of Cultural Ecosystem Services in Spanish Agricultural and Livestock Sectors: Metrics, Valuations, and Harmonization

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Cultural Ecosystem Services (CES) play a pivotal role in rural areas, although their contributions are less well recognized. Linked to this, their valuation and quantification often receive less attention than provisioning and regulating ecosystem services. Recognizing CES enhances our understanding of the full spectrum of benefits derived from rural areas where economic activities coexist with high natural values (e.g. extensive livestock systems).

Metrics for CES are essential for comprehensive Ecosystem Service Assessments (ESA), enabling policymakers and stakeholders to make informed decisions regarding land use and sustainable economic strategies. Although quantification of ecosystem services is challenging due to the diversity of contexts and variety of stakeholders, as well as local conditions that impact cultural values, perceptions and identities, monetary valuations provide a common unit of measurement (i.e. €/ha) that facilitates communication and comparison of different ecosystem services contributions. Also, incorporation of CES valuation into the Life Cycle Sustainability Assessment (LCSA) framework enhances comprehensiveness, allowing for a more holistic understanding of the environmental, economic, and social implications of main activities in rural areas.

A literature review was carried out to assess the current state of knowledge on CES including papers from 2015 to 2024 (i.e. 10 years) with focus on the livestock and agricultural productive sectors in Spain. Although, the review highlights the diversity of values, there is a consensus on the importance of CES and their measurement. However, a diversity of valuation approaches and methodological strategies have been adopted, so by synthesizing the existing literature and identifying best practices, this review serves as a basis for future research, harmonization and policy development.

Guidelines and harmonization efforts are crucial to ensure consistency and comparability in CES assessment across different regions and ecosystems. Harmonized methodologies promote transparency and reliability in CES valuation, supporting evidence-based policymaking and conservation efforts. Additionally, guidelines aid in the integration of CES considerations into broader ecosystem management frameworks, fostering sustainable agricultural and farming practices that prioritize cultural values alongside economic and ecological objectives.

2.03.P-Tu015 Integrating the Effect of Wheat–Chickpea Rotation on the Provision of Ecosystem Services in the Life Cycle Assessment Methodology

Sara Lago, University of Santiago de Compostela & Contractica SL; Maria Teresa Moreira, University of Santiago de Compostela; Sara González-García, Universidade de Santiago de Compostela.

Ecosystem services are essential contributions of nature to our survival and well-being, supporting human activities from primary to tertiary sectors. The analysis of human activities to reduce their impact on the environment is crucial, but equally important is the analysis of their impact on ecosystems to enhance their capacity to support the ecosystem services provided by the surrounding nature. Agriculture plays a key role in the functioning of ecosystems, and the way agriculture is practiced has a significant impact on the environment and related services. Crop rotation is an ancient practice recognized to bring numerous ecosystem services, including N fixation, pest regulation, and yield increments.

The aim of this study is to evaluate the impact on ecosystem services of wheat in rotation with chickpea in Apulia (Italy) and to compare it with wheat monoculture. The environmental impacts will be integrated into the Life Cycle Assessment (LCA) framework by defining characterization factors (CFs) that will allow the identification of trade-offs between different environmental areas of concern throughout the life cycle, in addition to determining the potential for mitigating environmental impacts of the analyzed agricultural practices and whether they exceed the carrying capacity of the ecosystem.

Three land-related ecosystem services were analyzed, including soil erosion prevention, water purification, and carbon sequestration, taking into account land transformation and occupation drivers. The ecosystem services were quantified using site-explicit models, and a reference state scenario, the quasi-natural land cover of the region, was considered to calculate the CFs. Their calculation required a variety of data and datasets, including the Copernicus Land Monitoring Service and European Soil Data Center databases, as well as climatic, topographic, and edaphological data. Measuring the impacts on ecosystem services and integrating them into the LCA framework provides valuable insights for identifying agricultural practices that not only reduce the environmental impacts, but also support the performance of ecosystems and their functions in a given area.

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2.03.P-Tu016 Regional Landscape Connectivity: a Complementing Layer for Life Cycle Impact Assessments

Emke Vrasdonk, Swedish environmental research institute (IVL); Henrik Johansson, Swedish environmental research institute (IVL); Tomas Rydberg, IVL Swedish Environmental Research Institute; Stina Dellås, IVL Swedish Environmental Research Institute.

Background and Purpose: The European Commission's Product Environmental Footprint (PEF) methodology quantifies environmental impacts of products but neglects direct biodiversity impacts from land use. The LANCA® framework, mandated for PEF studies, primarily addresses soil quality without considering biodiversity explicitly. As introduced by Maier (2024), The recent BioMAPS method offers a multi-scale approach to biodiversity,

considering various land use activities and their impacts across different scales. This method integrates well within the existing LANCA® framework but requires refinement, especially in modelling biodiversity risks at the landscape level. We propose adding a new layer to assess regional biodiversity risks which will complement the global and local risk evaluations as provided by BioMAPS.
Methods: This new layer is developed through the application of landscape ecological models to evaluate landscape connectivity, crucial for biodiversity conservation. By integrating core habitat data and assigning friction values to different land use classes, this layer assesses the influence of land use activities on regional connectivity. The methodology will be tested through case studies involving bio-based materials to evaluate its practical application and identify potential improvements.
Results: Preliminary results indicate that this new layer can complement the existing BioMAPS method by identifying biodiversity risks associated with different land use types. This approach aims to refine the assessment tools available within the current PEF framework, although it also underscores the ongoing need for more detailed species-specific and spatial inventory data.

Conclusions: Through this EU-funded CALIMERO project, our initiative furthers the integration of biodiversity considerations into life cycle assessments by proposing a new layer that complements existing methods. This development refines the BioMAPS method with a landscape configuration focus, thus offering a more comprehensive framework for biodiversity assessments within the PEF framework, supporting more sustainable environmental management and policy decisions.

2.03.P-Tu017 Urban Vegetation to Regulate Air Quality: Assessment of the Effects on Plants and Humans

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Vegetation can absorb ozone (O3) through their stomata, hence reducing air concentrations and potential human health impacts. However, plants are themselves affected by O3, which can in turn reduce their pollution mitigation capacities. Existing studies usually focus on these two aspects separately. We aim to combine both and a) evaluate the effects of O3 on plants and hence on their mitigation capacities and b) quantify the gain of O3 reduction on human health using damage indicators. We study different scenarios of a site located in Strasbourg: no vegetation, reference or high vegetation and reference or high background O3 levels. Based on plant-atmosphere-built areas exchange mechanisms, canyon and canopy O3 concentrations are evaluated. Biomass loss as a function of Phytotoxic Ozone Dose (POD) is integrated to the model. The latter remains under 2%. Compared to the no-vegetation scenario, vegetation leads to a decrease of 4 to 6% in O3 canyon concentrations and 34 to 40% in canopy concentrations. High vegetation scenarios lead to a higher decrease. We couple the model with an intake and impact pathway approach based on the Global Burden of Diseases Injuries and Risk Factors Study to evaluate the consequences on human health. Human intake by inhalation decreases by 4 to 6% in the canyon and 31 to 36% inside the canopy. Under high O3 concentrations and no vegetation, human health impacts are of 0.0018 DALY, but for all other scenarios, the mean concentrations are below the theoretical minimum level where effects are observed. Our results indicate that urban vegetation can have significant effects on pollution mitigation, especially if exposure occurs under the canopy, which is mainly the case for trees. The effect of O3 on vegetation is limited to 2% in our scenarios, but studies show that effects are higher for higher POD and models are dependent on vegetation species. Results are thus site-specific, and likely to change according to on background O3 levels, vegetation type and vegetated area. Finally, considering that emissions under the canopy can remain trapped and lead to high exposure concentrations, cities' greening should be accompanied by strategies limiting air pollutant emissions. The proposed framework can be used for decision-making in urban projects, and integrate other ecosystem services of urban vegetation such as well-being and temperature regulation.

2.03.P-Tu018 Life Cycle Assessment on an Algae-based Cosmetic and the Effectiveness of Results Communication

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The study aimed to analyze the environmental impact of algae-based cosmetic products and investigate communication strategies with non-LCA experts. Environmental degradation due to cosmetics has been subject of concern in recent years. Bio-based alternatives, such as metabolites extracted from algae, have therefore been of growing interest to the cosmetic industry. To our knowledge, a life cycle assessment (LCA) study on an algae-based moisturizing cosmetic product has not been published so far. It is important to identify improvement points in processing these materials now, as this sector is in its infancy. Since the environmental performance of a product plays a role in purchase behavior, it was also analyzed how results of LCA-based methods can effectively be communicated to the consumer.

A life cycle analysis based on industry data was conducted using a cradle-to-grave approach. The focus of the impact assessment was on nine impact categories. A literature research was conducted to identify visual communication tools in LCA methods, and design strategies were consulted to assess them.

The overall global warming was 0.858 kg CO2e with the use phase contributing 52 % of the product's burden. Algae cultivation and post-treatment had only a minor impact below 0.01 %. The most severe ingredients of the moisturizer itself were sodium alginate and glycerin. Replacing the PP-bottle with post-consumer resin would decrease the product's impact to 0.809 kg CO2e.

Found studies that tested consumer communication tools focused on comparative approaches. Labels with color schemes were mostly suggested. In some, effectiveness would likely fail due to unclear use of codes. Product claims and standard graphs were disussed for non-comparative assertions.To conclude, for internal decision-makers, focusing on replacing the current primary packaging with recycled alternatives would lead to a significant reduction of burden. Consumers should focus on applying the product in small amounts, as indicated by the company, and reduce water usage during face washing, as this will lead to the greatest reduction of burdens.

Communication tools for comparative results have been well studied. However, a final tool that covers trust, understanding, and consumer purchase has not yet been found. More research should be done on communicating non-comparative results and consumer information on less known impact categories.

2.03.P-Tu019 Is Life Cycle Assessment Ready To Integrate Biodiversity Effects of Seafood Production?

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Environmental Research Institute; Jean-Baptiste Thomas, KTH Royal Institute of Technology; Sara Hornborg, RISE Research Institutes of Sweden, Department Agriculture and Food.

Purpose
Halting the decline in biodiversity is a major global challenge. An important driver of biodiversity loss, especially in the oceans, is seafood production. Consequently, there are increasing ambitions to integrate biodiversity impacts into Life Cycle Assessment (LCA), a method that is widely and increasingly used to quantify environmental performance of seafood. The aim of this study was to evaluate how valuable and mature existing methods in LCA are for addressing marine and freshwater biodiversity loss from seafood production and to recommend actions towards better inclusion of biodiversity in LCA to practitioners and researchers.
Methods
This study compiled and synthesized data on environmental concerns related to seafood production and available Life Cycle Impact Assessment (LCIA) methods for addressing aquatic biodiversity impacts through a literature review. In a next step, we evaluated how useful LCA presently is for capturing biodiversity concerns from seafood e.g. in terms of geographical coverage and level of skill end effort required from a practitioner.
Results
We identified 39 environmental concerns linked to seafood production of which 90% could be categorized as causing biodiversity loss. We found that there were LCIA methods available to quantify half of the concerns, but, only one fourth of the concerns have so far been included in LCAs of seafood. The available methods were, however generally focused on impact on species level, and on pollution and climate change, rather than the major drivers of marine biodiversity loss: exploitation and sea use change. In addition, the low operational level and limited geographical coverage of LCIA methods could potentially hinder their application.
Conclusions
Although most of the environmental concerns related to seafood production can be categorized as causing biodiversity loss, LCA captures biodiversity impact poorly. This analysis provides an extensive overview of which environmental concerns should be taken into account in a seafood LCA and which methods are available. We further evaluate how applicable the methods are for a practitioner depending on studied system, geographic area and dataset. In order to better include aquatic biodiversity impacts in seafood LCAs, the most important recommendation for LCA practitioners is to address all relevant concerns quantitatively, where possible, and for research to prioritize method development concerning exploitation and sea use change impacts.

2.03.P-Tu020 Exploring Evidence-Informed Policy Making for an Environmentally Sustainable Blue Economy

Sue Ellen Taelman, Ghent University; Laura Vittoria De Luca Peña, Ghent University; Jan Staes, Antwerp University; Ine Moulaert, Flanders Marine Institute; Sara Vandamme, Ghent University; Johanna J. Heymans, European Marine Board; Jo Heymans, Ghent University.

Background and purpose
While the global ocean is experiencing escalating exploitation driven by human demands, it faces major environmental consequences. Policy instruments can play a crucial role in accelerating sustainable growth for the Blue Economy, but it is questioned to what extend they provides sufficient guidance to relevant stakeholders. This study aims to analyze the (lack of) uptake of comprehensive and quantitative environmental impact assessment tools in legislation supporting the sustainable growth of ocean-based activities, and shows the importance of such tools by means of application to a multi-use offshore case.

Methods
Diving into the historic and dynamic landscape of marine policy, this research analyses key legislation aimed at promoting the sustainable growth of the Blue Economy, elucidating their effectiveness in addressing environmental sustainability concerns. In particular, the integration of ecosystem services and life cycle assessment methodologies within existing legislation to evaluate environmental impacts comprehensively, is explored. To demonstrate the applicability of a life cycle and ecosystem-based methodology, the environmental sustainability of a co-locating offshore wind energy and mussel farm in the Belgian North Sea was quantified.

Results
An analysis of current legislation reveals a notable gap in providing guidance on consistent methodologies for measuring sustainability impacts. To address this deficiency, the study advocates for the uptake of quantitative and comprehensive environmental sustainability impact assessment methodologies, integrating ecosystem and life-cycle-based approaches, in legislation, offering a systematic framework for assessing environmental sustainability within the context of marine activities. The findings of the case study indicate that the positive impacts of these activities significantly outweigh the negative ones, primarily attributed to the benefits derived from offshore renewable energy. The analysis also identifies areas for enhancing the methodology to better align with policy objectives, and explains the science-policy interface as a co-learning environment.

Conclusion
This study underscores the importance of employing scientifically rigorous methods to inform policy decisions in marine resource management. The research aims to support evidence-informed policymaking and contribute to the sustainable development of the Blue Economy while safeguarding marine ecosystems.

2.03.P-Tu021 A Novel Approach for Land Use Impact Assessment in Past and Present

Marta Galindo Díaz, KU Leuven; Bart M Muys, KU Leuven; Jeroen Poblome, KU Leuven; Stef Boogers, KU Leuven.

The use of land has played a crucial role in the development of current and past human societies. However, increased human welfare and well-being due to land use have harmed ecosystem integrity in terms of structure and function. Among the different tools that have been developed to quantify human impact, Life Cycle Assessment (LCA) assesses the impacts associated with all life stages of a product or service. However, conventional LCA methods overlook the impacts of land occupation for several reasons: 1) a lack of accepted conceptual framework for selecting impact indicators; 2) a need for standardized characterization methods; 3) simplification of impact pathways; and 4) a lack of regionalized data.

The proposed methodological approach is embedded in ecosystem thermodynamics, describing ecosystems as open systems evolving into complex forms by increasing their structural organization. Due to their intricate structural complexity, ecosystems can increase their exergy dissipation, improving their buffering function against disturbances. Human use of land often results in reduced structural complexity, and related loss of buffering function. However, humans rely on ecosystem integrity, as their well-being depends on the provisioning, regulating, and cultural services that ecosystems provide. The ecosystem service cascade is a suitable framework to assess the cause-effect chain between human land use, its impacts on ecosystem structure and function, and ultimately the potential of ecosystem services provision. This study develops both generic and context-specific characterization factors (CFs) organized hierarchically along the cascade to study the impact on ecosystem structure and function. Changes in ecosystem integrity will be measured using various levels along the impact chain, depending on data availability and scientific knowledge regarding the impact pathways. CFs will be developed depending on biogeography and land use intensities. To select a list of indicators, key ecosystem structural elements and functions, such as species diversity or erosion control, along with their relationships, will be studied. To illustrate the method, the impact of agricultural and forestry land use for household cooking during Roman Imperial (end of 1st c. BCE-3rd c. CE) and current times in southwestern Anatolia will be studied. This method will assess the explanatory power of indicators and the acceptable level of detail in the impact pathway in data-poor contexts.

2.03.P-Tu022 Sea Use Characterization in LCIA: The case of shellfish farming at Thau Lagoon, France

Catherine Lalongé, CIRAIG / UQAM - ISE; Valérie Derolez, Ifremer-Marbec; Danielle Maie de Souza, Université de Montréal; Cécile Bulle, CIRAIG, École des sciences de la gestion, UQAM.

Background and purpose
Marine and coastal ecosystems encompass a wide range of habitats. Our understanding of those environments is limited. Anthropogenic activities are exerting unprecedented pressures on marine environments. Life cycle assessment (LCA) is ideally suited for quantifying the impact of our actions, as it provides a better understanding of the potential environmental impacts of our decisions. However, marine ecosystems are underrepresented in existing LCIA methodologies. The impact category of sea use (SU) is absent from LCA, which constitutes a major blind spot. This work constitutes a first approach to account for potential impacts of SU on ecosystem quality (EQ) by calculating characterization factors (CF) in the specific case of shellfish farming in the Thau lagoon (TL).
Methods
For consistency purposes, the SU methodological framework builds on the land use model developed by Milà i Canals et al. and the methodology of de Baan et al. for EQ.
A mechanistic approach is used to calculate the CF for the shellfish farming on TL. A cause-effect chain was defined to represent the environmental mechanisms induced by SU. For each impact pathways we identified the mechanisms at work to understand which species functional traits made them potentially vulnerable via that specific impact pathway.
We drew up a representative list of the species present in the lagoon and then identified whether they could potentially be affected by the different impact pathways.
We then calculated the potentially affected fractions of species (PAF) for SU occupation and transformation CF for shellfish farming in TL.
Results
426 taxa were identified, and five impact pathways were taken into consideration: seabed destruction, loss of seagrass beds, impact of new structures presence, shading and increased food supply. The CF for Sea occupation and transformation for the shellfish farming activity at TL are provided below.
Impacts - CF - Units
Occupation: 0.7559 PAF.m2.an / m2.an
Transformation: 2.18 PAF.m2.an /m2

The results for the case study show that a large proportion of the organisms present in TL are affected by the installation or the shellfish farming structures themselves.

Conclusions
These CF lays the groundwork for integrating the Sea Use impact category in Impact World+. The case of shellfish farming in Thau demonstrates the feasibility of the approach and illustrates how it can be operationalized. This research leads to the integration of SU in LCA.

2.03.P-Tu023 Synthesizing Landscape of Approaches for Biodiversity Footprinting for Private and Public Sectors

Ira Bhattarai, Natural Resources Institute Finland; Karin Morell, RISE Research Institutes of Sweden.

Background and Purpose

There is an increasing number of methods to calculate and disclose organizations' impacts and dependencies on biodiversity. The aim of our study was to get an overview of available methods and display parameters such as their scopes, outputs, and potential applications for businesses. Parallelly, we examined understanding and needs linked to biodiversity footprinting (BF) and disclosure among companies and cities. This was made within the EU Horizon project CircHive, which explores how Life Cycle Assessment (LCA) can be integrated with natural capital accounting (NCA) and fill each other's data gap in BF.

Methods

We reviewed 45 methods for biodiversity footprinting with focus on LCA, NCA and input-output models (I/O). The aim, methodology and implementation examples were described for each method and further classified into different categories to describe their characteristics (e.g., assessment type, focus, scope, input, output). Furthermore, we analyzed the methods' business applications (e.g., product and/or site focused, value- and/or supply chain focused etc.). To enable further understanding of the methods' applicability, we conducted a survey with project industrial stakeholders to examine their practices and needs.

Results

We provide a concise overview of different methods, primarily based on the scope of the business application. Different approaches had their own typical uses, strengths, and weaknesses. LCA-based methods were mostly focusing on product or production process. NCA-based methods were mostly used for valuing ecosystem assets, extent, and condition of some geographical area, e.g., country, region, or production site. I/O-models, together with LCA, enable assessments on the whole value-chain or business portfolio. Further, the methods varied a lot in assessment type, scope, and applicability. Generally, the species global extinction rate impact and land use/land use change are covered well whereas other aspects/drivers have gained less attention.

Conclusions

The study highlighted the inconsistencies in the biodiversity concepts, data access, and even more what are the data requirements as the key challenges in BF. There is a need for clear easy guidelines for the organizations on the basic concepts, their usefulness, practical implementation and what they mean for the organizations.

2.04 - Social Life Cycle Assessment: Priorization, Disaggregation and Contextualization of Subcategories and Impacts

2.04.T-01 Assessing Social Aspects of Biobased Value Chains
Nirvana Angela Marting Vidaurre, Luxembourg Institute of Science and Technology (LIST); Claudia Bieling, University of Hohenheim; Iris Lewandowski, University of Hohenheim.

This work aims to develop an integrated methodology to assess the social aspects of biobased value chains, specifically focusing on lignocellulosic perennial crops like miscanthus. While numerous studies analyse the environmental performance of such crops, few have addressed their social dimension. Existing social assessment frameworks provide extensive lists of impact categories with a limited context-specific analysis. This work proposes an approach that combines context-specific analysis of the foreground system and a generic assessment of the background system. In a first study, relevant social aspects for biobased value chains were identified through a literature review, revealing aspects often assessed but also those potentially overlooked in existing guidelines. Second, farmers in a region of Croatia were surveyed to determine their valued aspects and assess feasibility of miscanthus cultivation in the region. In a third study, the SOCA approach combined with EXIOBASE 3 was used for a regionalized social risk assessment. Results from this work indicated that the existing guidelines in S-LCA adequately cover social topics relevant to biobased value chains but lack attention towards smallholder and family farm stakeholders. The work emphasizes the significance of these stakeholders and proposes criteria for their consideration. Interviews with farmers highlighted valuation of aspects like health & safety, access to water and land rights, income, local employment, and food security. Adoption of miscanthus cultivation depended on market establishment, good trading conditions, profitability, subsidies and low input requirements. Barriers included land conflicts and availability. The main contribution of this study is the development of an approach that provides guidance for assessing the foreground and background systems of biobased value chains. This consists of a local perspective and a value chain perspective of not yet established value chains. The methodology and framework developed serve for the early identification of potential social impacts in biobased value chains, specifically agricultural value chains taking into consideration farmers' perspectives.

2.04.T-02 Identifying the Focus in Social Life Cycle Assessment – A Comparison of Different Prioritization Approaches of Social Impact Categories
Daniela Groiss-Fuertner, Wood K plus - Kompetenzzentrum Holz GmbH; Hanna Sofia Leiter, Wood K plus; Lea Maria Ranacher, Wood K plus; Franziska Hesser, Wood K plus.

In recent years, more and more attention is laid on Social Life Cycle Assessment (SLCA), to ensure a holistic view of sustainability. Social and socio-economic impact (sub-)categories and indicators are the centerpiece of SLCA studies, as the outcomes and their significance and reliability is strongly depending on the selected topics. A variety of social implications are possible depending on a wide range of variables and including both positive and negative effects and no universally valid and standardised method for selecting topics and impact categories in SLCA is known. A comparison of three different SLCA prioritization case studies is presented in this work, which includes the following approaches: (1) a multi-method approach combining literature review on different levels for the collection of indicators, stakeholder engagement with online surveys for prioritization of impacts and the utilisation of the Social Hotspots Database Risk Mapping Tool for hotspots identification; (2) an expert's based approach including basic literature review and outcomes of a workshop in a World Caféformat for prioritization of topics; (3) an expert's based approach including basic literature review and a qualitative interview approach for determining and prioritization of social implications of emerging technologies still on a very low technology readiness level (TRL) with limited preliminary studies and knowledge of the actual processes. The outcome of the study shows that literature reviews are predominantly used for selecting topics and indicators in SLCA. However, this method lacks in specifications on the system under study and it's not possible to determine the relevance of the single topics. Engaging stakeholders to obtain their perspectives into the prioritization process allows a more specific view and enables to include additional topics which are geographical-, sector- or process-specific. The results of the different prioritization approaches on different case studies allow to conclude on the potentials and challenges of the applied methods. Experiences show that higher specifications in the prioritization and selection of impact categories are necessary to obtain reliable assessments with the underlying objective of making a system more socially equitable.

2.04.T-03 Mapping the Terrain: Guiding Methodical Decisions in Social Life Cycle Assessment
Martina Zimek, Department of Environmental Systems Sciences, University of Graz; Sarah Wünscher, University of Graz; Rupert J Baumgartner, University of Graz; Claudia Mair-Bauernfeind, University of Graz.

Social Life Cycle Assessment (SLCA) is a method used to assess the social impacts of products and services throughout their life cycle. SLCA faces methodical challenges such as subjectivity, complexity, and data availability. The identification and prioritization of stakeholders, social impacts, and SLCA methods can be subjective, and obtaining reliable social data, especially for global supply chains, can be challenging. Additionally, there is no standardized procedure for prioritization methods in SLCA, leading to unstructured assessments. Various methodical approaches have been introduced to investigate social impacts, but an overview and categorization of these methods are lacking. To address these challenges, a structured literature review combined with a morphological analysis (MA) is conducted. The MA involves the following three steps: (1) identification of the dimension, (2) identification of different options (variants), and (3) evaluation of the logical consistency of each combination of parameters to narrow down feasible solutions by a cross-consistency assessment (CCA). The review analyzes approximately 100 scientific publications focusing on the identification and prioritization of affected stakeholders, social topics, and methods in SLCA. The combinations of variants show that sustainability questions guide the selection of specific SLCA methods, such as using the SHDB or PSILCA database for identifying social hotspots. With regard to the identification of social issues, the most commonly used methods include literature research, stakeholder consultation (interviews, surveys), and reliance on guidelines (such as the UNEP 2020 guidelines) and databases. This is similar with regard to the choice of method for stakeholder identification. With regard to topic prioritization, initial results already reveal a more heterogeneous mix of different methods, such as Multi-Criteria Decision Analysis, Best-Wors Scaling, stakeholder consultation, and materiality assessment, amongst others. Based on the results of the literature review, a step-by-step framework will be developed that supports the identification of relevant social topics and suitable methods when conducting SLCAs. Future studies should validate the framework by analyzing different scenarios based on the identified combinations. Overall, the study contributes to advancing SLCA methodology and supporting the development of socially responsible products and processes.

2.04.T-04 Social Life Cycle Assessment of an Emerging Technology: A Case study on Circular Flexible Plastic Packaging

Anna-Sophie Haslinger, Ghent University; Sophie Huysveld, Ghent University; Erasmo Cadena, Ghent University; Jo Dewulf, Ghent University.

Emerging technologies play a crucial role in addressing challenges associated with the transition from a linear to a circular economy. In the domain of circular flexible plastic packaging, efforts encompass the enhancement of collection infrastructure, sorting and recycling technologies and adopting circular design principles to enable the circular use of polyethylene post-consumer recyclates. However, the integration of social aspects within this context is limited, as is the guidance on prospective Social Life Cycle Assessment (S-LCA). Following the S-LCA principles, this study aims to conduct an entry-level assessment of an emerging technology for circular flexible plastic packaging as a case study. Furthermore, the study seeks to develop strategies for addressing challenges regarding the inventory of new technologies. The methodology involves key steps, including defining the objective and scope, collecting life cycle inventory data, conducting impact assessment, interpreting results, and formulating methodological strategies to guide practitioners based on findings. The scope includes various stages of the innovative life cycle, including: collection, state-of-the-art sorting and tracer-based sorting, pretreatment, selective dissolution and/or deinking and delamination, recompounding and deodorization, laminate, and packaging production in Europe. The inventory is based on primary data concerning the nine most material indicators prioritized by involving systematic literature review, multi-criteria decision analysis, and stakeholder engagement, as detailed in a previous publication. The present study outlines the results of the social hotspot analysis based on the defined performance reference points for impact assessment, focusing on those nine social indicators. It identifies Existence of record of proof of age and Existence of research and development (R&D) as the primary hotspots, revealing the absence of data for the upstream supply chain or non-disclosure, respectively. Additionally, methodological strategies are formulated to manage challenges arising from evolving technologies, such as inaccessible inventory data and data uncertainty. In future research, these strategies could guide S-LCA practitioners across various industry sectors in evaluating the social performance of emerging technologies and contribute to the development of a methodological framework for prospective S-LCA.

2.04.T-05 Social LCA of Recycled Textile Fibres: The Case of New Cotton

Diego Penaloza, Research Institutes of Sweden RISE; Torun Hammar, RISE Research Institutes of Sweden; Anne-Charlotte Hanning, RISE Research Institutes of Sweden.

The goal of this study was to explore the potential social effects and identify hotspots of the chemically recycled cellulose carbamate fibre and one garment made partially of this fibre. The assessment follows the UNEP SETAC Guidelines for Social Life Cycle Assessment, and the framework proposed as part of the PSILCA database. This includes a wide range of more than forty indicators among four stakeholder groups; workers, local communities, society and value chain actors. The system boundaries for the assessment were cradle-to-grave; including collection of textile waste, sorting, pre-processing, transport, carbamation, dissolving and filtration, wet-spinning, after-treatment, bailing of the final regenerated fibre, yarn spinning, weaving, finishing processes, garment production, consumer use and end-of-life treatment of worn-out garments. The inventory data was based on data collected from the New Cotton Project partners, where the fibre-to-fibre recycling was based on a concept engineering for a future industrial cellulose carbamate technology plant in northern Finland (production capacity of 30 000 metric tonnes per year). The yarn spinning, fabric production and garment production were also based on primary data collected from the project partners. The data used to quantify the economic value of the commodities was obtained from online searches, while the social risk per process was obtained directly from the PSILCA database. The main hot spots identified in this study in terms of processes are the manufacturing of the garment and the upstream production of chemicals for finishing. At the fibre production level, the hot spots identified are the mining of ores for electricity production and the upstream production of some chemicals. In terms of stakeholder groups, the one with highest risk of being affected by the life cycle of the garment is workers. This is specially the case for indicators related to working conditions such as child labor, fair salary and trade unionism. Local communities have also significant risk of negative impacts, especially regarding access to resources like water and biomass. The results at the garment level are sensitive to the assumptions concerning type of fibre, more specifically whether it is recycled or primary. As for the social risks of the fibre recycling process, the results are highly sensitive to the assumptions concerning location of suppliers.

2.04.P - Social Life Cycle Assessment: Priorization, Disaggregation and Contextualization of Subcategories and Impacts

2.04.P-Tu024 Use of Participatory Tools in the Prioritization of Social Impact Subcategories in the Assessment of Clean Solid Biofuel from Encroached Bush in Southern Africa

Alexandre Souza, Swedish University of Agricultural Sciences; Paulus Shigwedha, Namibia University of Science and Technology; Joseph Pechsiri, Swedish University of Agricultural Sciences; Niclas Ericsson, Swedish University of Agricultural Sciences; Cecilia Sundberg, Swedish University of Agricultural Sciences.

Background and Purpose: In the social life cycle assessment (S-LCA), selecting impact subcategories is a crucial component of the social life cycle impact assessment (S-LCIA) phase. Projects with limited time and resources often face challenges in including numerous impact subcategories, making the prioritization of the most relevant subcategories essential for conducting meaningful S-LCA and generating relevant results for stakeholders. This study demonstrates the use of participatory approaches for prioritizing impact subcategories in the context of an S-LCA of clean solid biofuels produced from encroacher bushes in Southern Africa. The EU Horizon 2020 SteamBioAfrica project (GA 101036401) intends to produce a scalable and replicable technology platform to support a large-scale transformation of the widespread problem of invasive and encroaching biomass into a sustainable and secure source of bioenergy and biochemicals in Southern Africa. The project also addresses the effects of this novel bioenergy system on other environmental and societal challenges in the region, including climate change impacts, energy insecurity, water shortage, social inclusion, and unemployment.

Methods: Participatory tools, including brainstorming sessions, participatory subcategory ranking, and semi-structured interviews, were utilized to engage stakeholders across the entire biomass-based value chain in Southern Africa.

Results: This approach facilitated the identification of primary concerns and the definition of priority impact subcategories for each stakeholder category. For example, unemployment was one key concern to prioritize for smallholders, while supplier relationship is one of the most relevant impact subcategories for representatives of commercial farmers (value chain actor stakeholder category).

Conclusions: The use of participatory approaches proved valuable in identifying and prioritizing impact subcategories for the S-LCA, ensuring that the assessment of potential social effects is more authentic and relevant to local actors. Moreover, engaging stakeholders enhanced the understanding of the assessed system and its value chain, contributing to other phases of the S-LCA.

2.04.P-Tu025 Indicators for Assessing Use Phase Social Impacts from Swedish Wind Power – Informed by the Jädraås Windfarm

Elisabeth Ekener, KTH - Royal Institute of Technology; Lisa Holmqvist, KTH Royal Institute of Technology; Tilda Lundman, KTH Royal Institute of Technology; Léa Braud, KTH Royal Institute of Technology.

Countries around the world are shifting to more sustainable energy sources in order to address climate change, among them wind power. To assess the sustainability performance of a new energy source, it is important to also consider the social impacts, and apply a life cycle perspective. This is done with a Social Life Cycle assessment (S-LCA). To date, methods for assessing the use phase in S-LCA are lacking. This study aims at evaluating indicators for assessing use phase social impacts of land-based wind power in Sweden.

Through a literature review, an overview of use phase indicators applied in S-LCA was created. The indicators were then evaluated, selected and categorized, based on their relevance to land-based wind power in Sweden. Their applicability was discussed, based on an on-site visit in the case study wind farm at Jädraås.

The outcome is a list of 147 indicators, grouped into 10 main categories, deemed relevant for use phase assessment of wind power in a Swedish context. The broad list, and the categorization of the indicators, allows for adapting the selection of indicators to a specific study. A guiding document was created, to support the practitioner in making this adaptation.

The sustainability assessment of Swedish land-based wind power can by enhanced by offering a resource to practitioner to facilitate the inclusion use phase social impacts to a more comprehensive sustainability assessment.

2.04.P-Tu026 Social Life Cycle Assessment (SLCA) of a District Cooling Centre

Gerhard Piringer, University of Applied Sciences Burgenland; Raphael Schauer, University of Applied Sciences Burgenland; Doris Rixrath, University of Applied Sciences Burgenland; Rosa Weber, University of Applied Sciences Burgenland; Gilbert Zisser, Wien Energie GmbH; Stefan Buchner, Wien Energie GmbH; Buchner.

Background and Purpose

Understanding the social implications of energy infrastructure is a key consideration for developing a sustainable urban infrastructure. In this context, district cooling systems can be important components of climate adaptation. The study provides first results of a Social Life Cycle Assessment (SLCA) of an existing district cooling centre in Vienna, Austria.

Methods

The district cooling centre under study consists of three compression chillers and two district-heat powered absorption chillers. A hypothetical operation exclusively with compression chillers was analysed as well. The centre is modelled based on hourly operator's data from 2019 (last pre-CoViD year). Social impacts were quantified with the Soca v2.0 database and the Social Impacts Weighting Method that measures indicators with a "medium risk hours" metric. The functional unit is 1 MWh of cooling energy at the plant boundary, without the distribution network.

Results

Indicators of particular relevance as expressed in medium risk hours include drinking water coverage, child labor, illiteracy, anti-competitive behavior, and public sector corruption. For these four categories, preliminary findings point to the plant's operation as main social hotspots. Within this stage, the provision of electricity and district heat each contribute comparable impacts. Processes that contribute most include the provision of natural gas for district heat and the related infrastructure, as well as electricity imports and the construction of transmission and distribution networks. In the variant with only compression chillers, their electricity demand dominates (> 80 % of total impacts). The variant's impacts are lower than those of the existing centre by 5 % to 29 %.

Conclusions

While these preliminary results provide valuable insights into social impacts, they will need to be examined and expanded upon in future research. The study finds that the impacts of the operational energy supplies tend to dominate the selected social impacts, while manufacturing the infrastructure itself contributes less, if still substantially. Within the energy supply impacts, no single process dominates. Replacing the existing absorption chillers with compression chillers tens to decrease impacts somewhat. These results can help to inform planners and other decision-makers about the social sustainability of district cooling systems, ultimately contributing to a more socially responsible urban development.

2.04.P-Tu027 Prioritization of Indicators in Social Life Cycle Assessments: A Case Study in the Energy Storage Sector

Sarah Wünscher, University of Graz; Martina Zimek, University of Graz; Tobias Stern, University of Graz; Claudia Mair-Bauernfeind, University of Graz.

In the realm of sustainability assessments, there's a growing recognition of the need to include social dimensions alongside environmental considerations, with Social Life Cycle Assessment (SLCA) as a crucial tool for this purpose. However, there are many prevalent indicators available, but not all are relevant to a specific product system. The identification of relevant social topics is a first critical step in performing an SLCA. For this generalized and standardized methods are required. So far, limited research has been done that addresses the challenges of prioritization. This study aims to address this gap by reviewing methods for prioritizing social topics and assessing the involvement of stakeholders in the prioritization, particularly focusing on a vanillin-based active material i.e., Methoxyhydroquinone (MHQ), in an electrolyte for a redox flow battery system. To this aim, a three-step approach was carried out: (1) literature review to identify methods for prioritizing social topics; (2) focus group workshops to prioritize social topics by applying materiality analysis (MA) and (3) identifying hotspots with the social hotspots risk mapping tool. Using this combination of methods and triangulating the results, a limited number of relevant social topics for the SLCA of MHQ could be derived. The results of the literature review show different methods to be used for prioritization. Those methods were grouped into three categories, namely participatory approaches, decision-making techniques, and approaches from economics. From the review of frequently used topics in similar SLCAs, it became apparent, that the subcategories 'working conditions' and 'health and safety' of stakeholder group 'Worker' is the most present. As for applying MA to prioritize topics for SLCAs, the participants had different experiences when it came to the difficulty of evaluating the relevance of a topic. Especially concerning the stakeholder group 'Society' with the topics 'corruption' or 'public commitment to sustainability issues/animal welfare' was difficult to grasp and to prioritize. By actively engaging stakeholders and utilizing a multi-method approach, relevant social topics could be successfully identified and prioritized for assessing MHQ in ESS. Moving forward, refining methodological approaches, and fostering a common understanding of topics in stakeholder consultations will be crucial for further advancements in SLCA research.

2.04.P-Tu028 Delving into Frameworks for Social Life Cycle Assessment of Hydrogen-Related Products Based on Target Audience

Sumanth Maddula, IMDEA Energy; Javier Dufour, IMDEA Energy; Diego Iribarren, IMDEA Energy.

Fuel cells and hydrogen products arise as a key illustrative case of emerging energy-related products whose deployment is noteworthy and conditioned by their actual sustainability. This entails not only considering their environmental and economic impacts but also assessing their social implications. This underscores the importance of science-based social assessment approaches tailored to this type of products. Within this context, leveraging tools such as Social Life Cycle Assessment (S-LCA) can facilitate a holistic understanding of the societal implications of adopting hydrogen solutions at different levels. The goal of this work is to define S-LCA frameworks for hydrogen-related products tailored to target audience, ultimately contributing to comprehensively understanding and addressing the potential social impacts associated with these products. In particular, two different target groups were considered: decision-makers and citizens.

The two frameworks proposed in this work serve two differentiated purposes: (i) supporting decision-makers, and (ii) promoting interaction with citizens through enhanced reporting. Although the two frameworks involve four identical major stages, each suggested framework has its own unique set of characteristics. The materiality assessment is an important add-on feature to the framework designed for decision-makers. In addition to materiality assessment, social hotspot analysis and multi-criteria decision analysis are included. While all the features from the decision-maker framework are also applicable to the framework oriented towards citizens (reporting), an add-on feature that distinguishes the latter from others is the visualisation of results (dashboard).

Overall, this work on the social dimension of hydrogen-related products for decision-makers support and citizen-oriented reporting paves the way for an enhanced, science-based social acceptance of fuel cells and hydrogen technologies. Finally, it should be acknowledged that this work has been carried out in the context of the HYPOP project, which is supported by the Clean Hydrogen Partnership and its members. It is funded by the European Union (Grant Agreement No 101111933). Views and opinions expressed are however those of the authors only and do not necessarily reflect those of the European Union or the Clean Hydrogen Partnership. Neither the European Union nor the Clean Hydrogen Partnership can be held responsible for them.

Track 3: Life Cycle Management

3.01 - Integration of Life Cycle Assessment in Policy Deployment - Solving the Method and Data Challenges

3.01.T-01 Future Nordic Developments Through Learning from Successful Life Cycle Network

Maria Rydberg, Swedish Life Cycle Center/Chalmers University of Technology; Anna Wikström, Swedish Life Cycle Center; Yulia Liu, Swedish Life Cycle Center.

Introduction

The Swedish Life Cycle Center, established in 1996 and hosted by Chalmers University of Technology, is a center of excellence that fosters collaboration among academia, research institutes, industry, and government agencies. By gathering Swedish life cycle competence, it has been instrumental in development and adoption of the life cycle perspective in society, making important contributions to international initiatives. Insights, outcomes from collaborative dialogue groups and projects will be shared during the presentation.

Materials and Methods

To address challenges expressed by our partners the Center makes use of collaborative methodologies, bringing together diverse stakeholders. The Center's activities include regular meetings, workshops, seminars, and the establishment of working and expert groups as well av providing opportunities for networking and competence building. Three initiatives will be more thoroughly presented at the conference: Dialogue group for Government Agency Collaboration, Expert Group on Environmental Footprint and Nordic Dialogue Forum for LCA, Climate, and Buildings.

Results and Discussion

Operating as a neutral platform, the Centre allows for mutual project development and co-creation among researchers, practitioners, and decision-makers. The Center, by uniting Swedish life cycle expertise and leading companies, has played a key role in promoting life cycle approaches in Sweden's society, industry, and government agencies.

The Expert group Environmental footprint has contributed to a better understanding of the methods and their impact, both from a policy perspective and from an industry perspective. The dialogue group for government agencies has enhanced competence among agencies and influenced life cycle-based policies in Sweden. The Nordic Dialogue Forum for LCA, Climate, and Buildings has given highly valued input to the building authorities in the development climate declarations.

Conclusions

The Swedish Life Cycle Center has played a pivotal role in advancing LC methodologies and fostering collaboration among key stakeholders. Its work has significantly contributed to policy development, competence building, and the practical application of LCA. These findings underscore the relevance of the Center's work and its potential to drive future advancements in field. The opportunities created for mutual learning and capacity-building impact upon society and drive the life cycle field forward.

3.01.T-02 EU Regulations on the Modelling of Electricity and Residues

Tomas Ekvall, TERRA.

The EU Renewable Energy Directive (RED) specifies how to calculate the carbon footprint of biobased fuels to demonstrate that they meet the climate requirements of the Directive. Related Delegated Regulations include calculation rules for renewable fuels of non-biological origin and from recycled carbon. The EU Environmental Footprint (EF) methodology includes another set of calculation rules, and versions of these are to be used to demonstrate that photovoltaics (PV) and electric car batteries meet stated climate requirements. The calculation rules diverge, for example on how to model recycling and electricity supply. This presentation summarises and analyses the rules for modelling inputs of residual materials and electricity in the published and draft EU policy documents.

When modelling the use of secondary materials, the RED Delegated Regulation assumes a rigid supply, while the EF assumes a supply with some elasticity. Both are correct depending on the system boundary: the secondary resources are rigid, but the collection and utilisation of this resource are elastic at least to a degree.

The RED accounts for the alternative fate of the secondary material, while the EF accounts for the complementary need for primary material. Each capture half the picture: the use of recycled material is likely to have an impact both on the alternative fate of this material, and on the need for primary material in other products.

The documents include a multitude of rules for modelling electricity. The general RED applies straightforward location-based electricity modelling, while its Delegated Regulations apply different sets of special conditions for the calculations. The general EF document and draft PV regulation apply market-based modelling, but the draft battery regulation falls back to location-based modelling. Different ways to model electricity have pros and cons, and the choice of method is not straightforward.

3.01.T-03 Environmental Product Declarations in Procurements – Practical Experiences with focus on Concrete Sleepers

Kevin Sandberg, WSP Sweden; Susanna T Toller, The Swedish Transport Administration.

1. Introduction

The Swedish Transport Administration (STA) has implemented climate requirements in procurements to support the zero-emission target by 2040 and ensure that the agency's actions align with Sweden's and the EU's climate goals. Environmental Product Declarations (EPDs) have played a crucial role as verification documents in this work. This abstract aim to consolidate practical experiences of EPDs in the procurement process as well as highlighting success factors and challenges.

2. Methods

The abstract encompasses a compilation of the STA's procurement process and experiences with focus on concrete sleepers, combined with results from two semi-structured interviews with current suppliers.

3. Results

Climate requirements have led the suppliers of concrete sleepers to map and analyze their processes, define actions to reduce climate impact, and use a larger share of renewable energy. The use of EPDs as verification document has been successful due to i) Transparency: EPDs are third-party verified and publicly available through program operators, ii) Predictability: Common calculation rules ensure consistency, iii) Equity: Assessment is based on equal terms.

However, there are also some challenges associated with the use of EPDs as verification documents, e.g., the use of the Mass Balance Approach (MBA). This technique involves allocating flows with specific characteristics (such as inputs and outputs of biobased materials or recycled content) within the manufacturing process to specific products. There is not yet consensus among all program operators regarding the use of MBA. Hence, the STA receives EPDs with different approaches to MBA which affects the comparability.

The suppliers need to transform to climate neutral technologies to stay competitive and financial incentives will most likely be needed. It is yet uncertain to what extent this can be met by procuring organizations. To find a mutual approach for the different stakeholders that enables the necessary steps to be taken towards climate neutrality is an urgent issue for the years to come.

4. Conclusions

EPDs serve well as verification documents for climate requirements in procurement process. However, there are certain pitfalls such as inconsistent usage of MBA. When striving for climate mitigation, finding the right balance between climate transition and financial feasibility becomes crucial.

3.01.T-04 Assessing the Environmental Impact of Products: The Role of Data Quality in Ecolabels

Maëlys Courtat, University of Surrey, Unilever; P. James Joyce, University of Surrey, Unilever; Sarah Sim, University of Surrey, Unilever; Jhuma Sadhukhan, University of Surrey, Unilever; Richard Murphy, University of Surrey, Unilever.

LCA-based environmental rating ecolabels (ERE) have been developing rapidly across Europe in the past few years, with the aim of guiding consumers towards more sustainable choices. To ensure these labels promote adequate differentiation between products, robust data quality approaches are required to generate accurate, relevant, and comparable product ratings. This is a sizeable challenge considering ERE also require feasibility and adoption at scale to be successful.

Data quality in the context of ERE has broadly been approached as a dichotomy between 'primary' and 'secondary' data. In practice the picture is much more complex as LCA studies usually combine data gathered via different methods and from multiple sources, often relying on a mix of company specific activity data as well as third party life cycle inventory (LCI) datasets. In ERE, the use of specific product information (e.g. Bill of Materials) is an important consideration, helping to facilitate adequate product differentiation. In addition, the use of secondary LCI datasets is relevant to approximate the elementary flows associated with these materials, when supply chain specific data are unavailable. Their quality can however be heterogeneous and will be context (i.e., product system) dependent. We therefore identify a need to 1. Differentiate secondary LCI datasets efficiently based on context suitability (their 'representativeness level') to guide potential data choices in ERE; and 2. Evaluate how LCA results and ERE are impacted by these data choices.

To address these needs, we conducted a large-scale sensitivity analysis. LCA midpoint results were generated for 100 laundry detergent products using product/company specific activity data and secondary LCI datasets. This process was repeated for five distinct data scenarios, in which the datasets used to represent 19 key ingredients reflected different levels of data representativeness. Single scores summarising the products' environmental performance were derived by aggregating the results for each of the 500 LCA runs. In addition, categorical ratings (A-E) were awarded to products based on their relative performance within the portfolio. Results (midpoint, single score, and rating) were analysed to evaluate sensitivity to the data scenarios.

This study is the first to evidence how data choices influence product environmental performance ratings. Our work highlights the need to develop appropriate data quality approaches for ecolabelling.

3.01.T-05 Leveraging Digital Product Passports for Automated Environmental Impact Assessment Using an Information System

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1. Background and Purpose

RE-strategies (e.g. recycle, reuse, repurpose) play a vital role in the European Commission's aim of decreasing the use of primary raw materials in value chains. For the effective implementation of RE-strategies, information sharing along the value chain is critical. This is uniquely enabled by digital product passports (DPPs) introduced in the Eco-design for sustainable products regulation.

In this context, the Horizon Europe project CE-RISE aims to develop an information system that makes use of DPP data in order to enable the implementation of circular economy strategies for electronics and renewable energy products. As product environmental impact information is a crucial component needed for the identification of optimal RE-strategy and therefore for RE-strategy implementation, the CE-RISE information system will include an automatic environmental impact calculation procedure based on data included in DPPs.

In this work, we present a prototype of this environmental impact calculation procedure, which allows to calculate environmental impacts from life cycle inventory (LCI) information stored as individual data points in a DPP system, making use of a hybrid life cycle assessment (LCA) framework. We illustrate this functionality by applying it to a case study of PV panel production, using artificially created DPP data (i.e. three scenarios in Table 1). Within this, different options for modelling RE-strategies have been applied – i.e. the cut-off approach, the 50/50 method, and the circular footprint formula [1]. We present preliminary results and discuss identified open problems with this approach and their possible solutions.

2. Methods

2.1. System assumptions

We operate under the assumption that the DPP system includes the required process information, e.g. bill of materials and energy use, including their direct impacts, but not necessarily in a consistent format. We treat different cases, which vary in the amount of value chain actors included in the DPP system.

2.2. Outline of impact calculation process

The general envisioned process for calculating environmental impacts from LCIs stored in different product DPPs involves a number of steps:

- DPP collection. Given a product under study, the system needs to collect the DPPs for the value chain of this product, insofar as these are included in the DPP network (e.g. given the product under study is a PV panel, the DPPs for PV cells and silicon wafers need to be included).

- Foreground/background separation. Given the data points in the collected DPPs, the system needs to differentiate between interlinked processes (e.g. a PV panel requires PV cells, and the production of PV cells is included as a DPP) and background processes (e.g. the production of a PV panel requires electricity, which is not included as a DPP process).

- Connecting to the background dataset. The identified background processes need to be connected to the background dataset (e.g. the electricity required in LCI database needs to be connected to the "domestic electricity mix" category in the background dataset dataset). These may be named differently, requiring context-based category matching.

- Life Cycle Impact Assessment: Given the obtained full product LCIs and the related direct environmental impacts, the life cycle impacts need to be calculated.

2.3. Outline of illustrative case study

We illustrate our envisioned process by performing an environmental impact assessment on a single-crystalline silicon PV panel. Using LCIs collected as part of IEA PVPS Task 12 [2], we firstly create hypothetical DPPs in a format aligning with that of a DPP provider. We secondly illustrate all steps of the process outlined in Section 2.2 using this data and using as background dataset the hybrid version of EXIOBASE 3 [3].

We will perform the impact assessment under the cut-off approach, the 50/50 method and the Circular Footprint Formula [1] for the RE-strategy of recycling.

3. Results

Preliminary results indicate that the level of detail in the DPP and the availability of LCI data directly affect the uncertainty of the results. A detailed DPP and good LCI data lead to low uncertainty, whereas a lack of detailed information and reliance on background databases like EXIOBASE 3 increases uncertainty.

- Extensive data requirements

To enable calculations of environmental impacts, and furthermore, social and economic impacts, the relevant process information needs to be supplied to the DPPs by the producers of both the products under study, their components and materials, and their end-of-life treatment by the recyclers. This requires extensive data collection and extensive data storage capabilities. While the ability to show the impact of an applied RE-strategy might be enough incentive for this for producers, this may not be the case further down or up the value chain. As such, the information system should in some way be able to compensate for limited data availability. For individual products, this may be solved by including extra, openly available, LCI information in the system itself.

- Background data resolution requirements

Accurate calculation of environmental impacts through the hybrid LCA method requires a highly disaggregated background table. Our results show that the resolution of our background table is at the moment not sufficient. Current efforts in the CE-RISE project aim to increase the resolution of our background table for the relevant product components to lower the uncertainty level, but to be of use for a more varied collection of products, different background datasets are needed. In the development of this method, we have ensured that it is background database agnostic, so that different background databases can be used if they include more specific information.

4. Conclusions

The CE-RISE project aims to support circular economy strategies for electronics and renewable energy products by using DPPs to facilitate information sharing along value chains. We are developing an automatic environmental impact calculator that uses LCI data from DPPs, as demonstrated in a case study on PV panels. Detailed DPPs with comprehensive LCI data significantly reduce result uncertainty and lower CO2 emissions, while less detailed DPPs and reliance on background databases like EXIOBASE 3 increase uncertainty and emissions. Challenges include extensive data requirements and the need for high-resolution background data, which the project addresses by integrating additional LCI information and ensuring adaptability to various databases.

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3.01.P - Integration of Life Cycle Assessment in Policy Deployment - Solving the Method and Data Challenges

3.01.P-Tu029 Unlocking the Potential of Digital Product Passports for Quantitative Sustainability Assessments

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The digital product passport (DPP) represents an innovative concept aimed at facilitating data sharing among stakeholders across product value chains. Such a platform is gaining traction, particularly in industries aligning with new European union regulations, offering an opportunity to enhance sustainability assessments often hampered by a dearth of high-quality data. Industrial ecology (IE) is a study that focuses on the relationships between society, the economy, and the natural environment. Since its foundation, IE has provided tools and knowledge to support the sustainable management of resources and environmental impacts and investigate the unintended consequences of human activities. Here, we review the state-of-the-art of sustainability requirements in DPPs and critically discuss how this could support sustainability assessment, within the field of IE. We discuss some of the opportunities, challenges, and next steps that could be undertaken by the IE community in this realm. Moreover, we identify current gaps in DPPs that hinder even more comprehensive assessments oriented to ensure the sustainability of products, and we further highlight potential synergies with IE methodologies that could refine both the development and utilization of DPPs.

3.01.P-Tu030 Can Chained Life Cycle Analysis be Economically Viable?

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Chained Life Cycle Analysis (cLCA) is a novel LCA approach that aims to enable faster and more accurate analysis of environmental effects by building a distributed system in which the LCA is executed in several points of the production chain by actual chain actors using their primary data. A central advantage of the cLCA method is its ability to utilize data accumulated in all previous analyses. Hence, while cLCA entails a considerable initial investment into methodological and technological development, over time the unit cost of life cycle analysis becomes lower as more and more models and data from previous analyses can be utilized.
We present a stylized model describing the economic logic of providing the services of cLCA versus traditional LCA. We assume that a service provider executes life cycle analyses of various products for customers. We include three types of costs: investment cost, fixed cost, and variable cost. Provision of both types of LCA services incur a fixed cost and a variable cost, the latter consisting of labor costs of the LCA expert carrying out the analysis. We measure the variation in work needed for LCA runs in terms of calculation nodes, which consist of a process model and a few data inputs. Hence the variable cost is the product of the number of nodes, research time for one node and the wage of the LCA expert. Further, cLCA enables the utilization of previous work through accumulation of calculation nodes. Hence, we assume that as the number of analyses increases, the LCA expert's time consumption per analysis decreases. To compare profits of cLCA and traditional LCA over time, we apply discounting (corresponding to a 5 % annual discount rate) and assume that income per analysis is the same in both traditional LCA and cLCA. Economic parameter values are estimates based on expert elicitation. The function for the speed of calculation node accumulation was estimated from a simulated dataset and fits well with a logarithmic form.
Our initial results indicate that the variable cost of cLCA decreases strongly with the number of executed analysis runs. If the time horizon of the analysis is long enough, profitability parity with traditional LCA can be reached despite the initial cost. With the parameter values used in this study, we find that investing in cLCA is profitable if the number of analysis runs is at least in the range of 60 – 90.
Chained LCA has disruptive potential in the LCA industry but still some unsolved challenges.

3.01.P-Tu031 Overcoming Data Challenges in Realising the Circular Economy: Exploring the Role of the Digital Product Passport and Life Cycle Assessment

Damon Waterworth, Yordas Group; Raul Carlsson, RISE Research Institutes of Sweden.

The circular economy represents a paradigm shift towards sustainable practices, yet its implementation faces significant challenges. In recent years, Life Cycle Assessment (LCA) has emerged as a powerful tool and can support circular economy objectives by evaluating the potential environmental impacts associated with products (goods and services) throughout their life cycle. As businesses look to improve their environmental performance and increase their use of secondary materials, the need for reliable and comprehensive data to support decision-making has become increasingly crucial. Here, we consider the role of the European Union's proposed Digital Product Passport (DPP) as the foundation for an information-sharing ecosystem and explore how LCA study aims and approaches affect the types of data required for environmental modelling.

In 2024, a qualitative research project was conducted involving interviews with industry stakeholders, non-governmental organisations (NGOs), and consultants. The primary aim was to identify and understand the challenges and opportunities for realising the circular economy. All participants were asked the same questions, including their thoughts on the role of the European Union's (EU) Digital Product Passport (DPP) and the role of LCA tools.

Participants highlighted the growing need to incorporate environmental and circularity criteria into the early product design stage. However, a lack of reliable data at this phase was identified as a significant obstacle, hindering informed decision-making. The research also highlighted the evolving nature of LCA studies, with an increased use of anticipatory LCA approaches for modelling hypothetical future scenarios rather than the present. This temporal shift has implications for the types of data input required, underscoring the importance of aligning data collection efforts with the appropriate LCA approach.

The DPP was recognised as a promising foundation for an information-sharing ecosystem, facilitating access to comprehensive, real-time LCA data, for all stakeholders. When supported by industry standards and increased supply chain data transparency, the accuracy and relevance of LCA studies in driving sustainable practices and realising the circular economy's potential becomes apparent.

3.02 - LCA and Sustainable Consumption

3.02.A.T-01 Towards an Environmentally Sustainable Economy within Planetary Boundaries - A UK Case Study

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Maintaining economic growth within the ecosystem limits is pivotal for sustainable development. The Planetary Boundaries (PBs) framework has emerged as a critical tool for measuring the absolute environmental sustainability of global economic activities. The latest studies on PBs have revised the control variables (CVs) and safe operating space (SOS) for key Earth-system processes, highlighting that six out of nine boundaries are globally transgressed. Nevertheless, the transgressions of PBs at the national level and economic sectoral contributions to these exceedances remain unexplored. The present study aims to fill this knowledge gap by proposing a national-level PBs-based absolute environmental sustainability assessment (PBs-AESA) method.

The method focuses on eight Earth-system processes with twelve CVs, excluding 'novel entities' for which neither the CV nor SOS have been well defined. To address previous studies' limitations in CVs coverage and alignment, a new characterization factors (CFs) model is developed to align with the most recent iteration of the PBs framework. The CFs model is then employed to translate the national environmental footprints to metrics with respect to the updated CVs.

Sharing principles are applied to allocate the global SOS to the national share of SOS. The impact results are compared with the national share of SOS to determine the absolute sustainability level. The proposed method is demonstrated through a case study in the UK. Environmental Extended Multi-Regional Input-Output Analysis (EEMRIOA) and EXIOBASE database are used to derive the UK's national environmental footprints.

Results demonstrate that nine of twelve CVs have exceeded their limits, with climate change (energy imbalance and atmospheric CO2 concentration) and nitrogen flows suffering the most severe transgressions. Sectoral contribution analysis identifies agriculture and transport as the main contributors to climate change and ocean acidification PBs, while agriculture and manufacturing sectors significantly impact other PBs. In conclusion, mapping the UK's national and sectoral sustainability performance against PBs could offer insights for implementing technology pathways and policy strategies towards absolute sustainability. Furthermore, the proposed national PBs-AESA method, integrating CFs and EE-MRIO models, is potentially applicable across regions and sectors, facilitating a deeper understanding of absolute sustainability performance at the sub-global level, thereby supporting global efforts towards sustainable development.

3.02.A.T-02 A Framework to Estimate Consumption-based Life-Cycle Environmental Impacts of Regions and Cities

Joana Bastos, European Commission, Joint Research Centre (JRC); Riccardo Fraboni, Institute for Renewable Energy, Eurac Research; Rita Garcia, University of Coimbra; Leonardo Rosado, Chalmers University of Technology.

Policies and strategies to improve environmental sustainability in cities and regions have often focused on a single or on a limited number of sectors and/or subsystems, which may offer limited potential to significantly reduce their overall impacts. Integrated environmental impact assessment frameworks that can capture the overall environmental impacts associated with cities and regions, including all their inter-linked sub-systems, are needed to identify sectors and activities associated with environmental hotspots and/or opportunities with significant improvement potential. To support effective decision-making toward environmentally sustainable development, such frameworks should be holistic, consider a wide range of environmental impacts, and have a life-cycle perspective. This paper provides a systematic and comprehensive framework to calculate the potential life-cycle environmental impacts of consumption associated with regional and urban areas. It couples urban metabolism (UM) with life-cycle assessment (LCA), to estimate the life-cycle environmental impacts of the Autonomous Province of Trento, in Northern Italy, and of its capital city, Trento, in 2019.

The proposed framework draws on a state-of-the-art UM-LCA methodology that estimated environmental impacts of urban consumption with a cradle-to-gate approach, and extends it to estimate cradle-to-grave impacts of consumption. First, we developed a material flow accounting (MFA) model to estimate annual domestic material consumption in the region and city, for thousands of product types, organized into combined nomenclature product categories. Second, we selected representative product types, based on their consumption share in terms of mass, and added products that have been identified to be representative or to have potentially high environmental impacts. Third, we developed a life-cycle model for the overall regional and urban annual consumption and calculated potential environmental impacts for a wide range of impact categories (selected from the Environmental Footprint package), with a cradle-to-grave approach (incl. extraction, transport, production, use and end-of-life). We compared the results with those using a cradle-to-gate model, demonstrating the importance of including the use phase, particularly for urban systems and sectors related to buildings and transportation, which account for a large share of the overall impacts associated with regional and urban areas.

3.02.A.T-03 Climate and Health Impacts of 1.5°C Lifestyle Changes

Stephanie Cap, Leiden University; Arjan de Koning, Leiden University; Laura Scherer, Leiden University.

Technological change by industry alone will not be sufficient to meet the Paris Agreement's 1.5°C target. However, technological and socioeconomic developments can also influence the impact of sustainable lifestyle changes. Here, we assess the carbon footprint reduction potentials and individual health impacts of over 40 lifestyle change options in the years 2015, 2030, and 2050 for five European Union (EU) countries. We also evaluate the extent to which different combinations of these sustainable lifestyle change options can reduce household footprints to 1.5°C target levels.

We calculated the carbon footprint reduction potentials of lifestyle change options using EXIOBASE environmentally extended multi-regional input-output (MRIO) tables projected to the years 2030 and 2050, following a 1.5°C-compatible sustainable development scenario but excluding lifestyle change. The lifestyle change options were implemented in the MRIO model, considering physical layers where appropriate. We combined various lifestyle change options and adoption rates into lifestyle portfolios and assessed the resulting footprints against 1.5°C-compatible targets. Portfolios considering citizen preferences and rebound effects were also evaluated. Human health impacts of mobility and nutrition-related changes were measured by multiplying physical layers by corresponding characterization factors to express the impact of changes to diets or physical activity levels in disability-adjusted life years (DALYs).

Our findings reveal a dynamic relationship between lifestyle changes and broader trends in decarbonization. The impact of some lifestyle change options, such as energy-saving measures, were tempered by increased technology adoption, while others, such as heat pump installation, had a greater relative reduction potential as background systems decarbonized. Several '1.5°C lifestyle' portfolios were possible in 2030 for four of the studied countries. More drastic lifestyle changes and adoption rates would be required to approach 1.5°C target levels in 2050, although only two countries could meet the target. We expect that the lifestyle changes with the greatest carbon footprint reduction potentials per domain also offer some of the greatest health benefits. Our results highlight the importance of encouraging progressively more sustainable lifestyle changes over time and the relevance of assessing country and temporal variations in the impact of sustainable consumption changes.

3.02.A.T-04 High Carbon Footprints and the Road to Sustainable Consumption: A Luxembourg Case Study

Thomas Gibon, Luxembourg Institute of Science and Technology (LIST); Claudia Hitaj, Luxembourg Institute of Science and Technology (LIST).

Background and Purpose

The Grand-Duchy of Luxembourg regularly appears among countries with the highest per-capita carbon footprint. To understand this particularity, we propose here a three-fold approach, and analyze the country's household (HH) footprints through each angle. Finally, decarbonization pathways are designed, with interventions and their timeline, to reach net consumption-based net neutrality by 2050.

Methods

First, a bottom-up carbon footprint assessment, using average consumption flows in mixed units as a basis, provides a first estimate of the individual carbon footprint in Luxembourg. In this exercise, consumption statistics, such as car ownership, useful floor area, heating and electricity mix and specific consumption, etc. are coupled with life cycle emission factors from a (process) LCA database. Second, a top-down "naive" approach, using environmentally-extended IO analysis, is used to determine the consumption-based emissions of Luxembourg as a whole ; the EXIOBASE is used here to produce the footprint estimate. Third, a mixed approach consisting in using HH consumption surveys on the one hand, and EEMRIO multipliers on the other hand, is finally used to understand HH's consumption structure, their carbon footprint, and their variability within the country – with data from the statistics office of Luxembourg (STATEC).

Results

In addition to a clear gap between production-based and consumption-based greenhouse gas emissions, results also show substantial deviations between consumption-based emission calculation approaches. This is especially true between the naive top-down approach and the two others. The peculiar status of Luxembourg, with over 220000 cross-border commuters consuming goods and services during the day, as well as with an important phenomenon of fuel tourism, explains partly the deviation between top-down statistics and the sum of HH consumption. Yet, with an overall average of 39 t CO2/year, HHs are still found to be high emitters, in correlation with a high purchasing power. Expense data also reveals interesting traits of Luxembourgish HHs, e.g. with air travel contributing to a high footprint across all income levels – differing from EU HHs.

Conclusions

Designing decarbonization pathways also requires a consumption-based approach. But even then, various calculation approaches provide results that deviate highly – showing that footprint accounting should be considered with care.

3.02.A.T-05 Cleanliness is Relative, Laundering Absolute – How to Facilitate Assessments of the Rebound Effect Using LCA

Erik Klint, *Chalmers University of Technology.*

Technological aids often allow us to trade resources for time. Without the tedious work of cleaning clothes by hand, the washing machine has allowed people to spend more time on increasing household productivity and education. Unfortunately, behaviours are not static. Reduced costs, e.g. time requirements, often lead to increased consumption. Today, people in Europe own more clothes and wash them more frequently than at any other time in history. This extensive consumption also means that the environmental impacts from domestic laundering are higher than at any other time in history. Many initiatives trying to curb these impacts have repeatedly failed. These failures indicate an incomplete understanding of what motivates consumer behaviours and how to incorporate them properly in LCA. By synthesising the findings from three separate studies, I argue that laundering is mainly socially motivated and must be treated accordingly in the analysis.

Contemporary assessments of environmental impacts from laundering exclusively stem from a technical perspective. These LCAs assume that the function of laundering is the outcome of the technical aid, i.e., to clean a certain amount of clothes. This simplification leads LCA practitioners to believe that there is a way to influence how often consumers wash directly. Defining the function in this way fails to acknowledge that laundering is a means to an end. Most people wash because the laundry bin is full or because they need a specific item. In other words, it is a response to a need and not a motivation in itself. To better assess consumer products and services, we must expand the LCA methodology to include a social perspective on behaviours. From this perspective, the function of laundering can instead be identified as the function of clean clothes, i.e., being presentable in social situations. This more nuanced function necessitates the inclusion of a wider set of behaviours, such as buying new clothes due to loss of fit or persistent stains. The findings presented in this thesis come from research focusing on domestic laundering. The methodological implications are, however, relevant for all products or services consumed for reasons other than their direct technical capabilities. Hopefully, this thesis will enable better integration of behavioural sciences into LCA. In practice, this would mean treating behaviours as a systemic component that is socially motivated rather than a static value to be optimised.

3.02.B.T-06 Salvation by Substitution? Case Textile Markets

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Background and Purpose: Feedstock substitution can be one important means for reducing the disproportionate environmental load of the global textiles sector. The estimation of substitution effect relies on a host of market assumptions. Some of the most critical uncertainties include, which products substitute for which products, and to what extent. This study introduces a systematic framework for identifying the existence and rate of substitution based on microeconomic theory and econometric analysis.

Methods: Four datasets and three theoretical models were applied for a set of empirical model formulations. The theoretical models included i) a linear approximate almost ideal demand system (LA-AIDS), ii) a conventional demand equation quantifying cross-price elasticities, and iii) an ad hoc formulation quantifying the response of the consumption of RCFs to the consumption of alternative textile fibers. The empirical models for the latter two theoretical models included OLS in first differences, autoregressive distributed lag (ARDL), and vector error correction (VECM) models. The selection of empirical models was informed by tests for non-stationarity, cointegration, autocorrelation, multicollinearity, normality and heteroskedasticity.

Results: The results point to regenerated cellulosic fibers (RCFs) being imperfect substitutes for cotton with an empirical substitution ratio of 13-34%, and mostly independent from the demand for polyester with an empirical substitution ratio of 0-18%. With a substitution ratio of 1:1, the marginal substitution impact would be -2.17 tCO2eq./t. With the empirical substitution ratios, an additional unit of RCFs produced may lead to an increase of fossil emissions, ranging from -0.27 to 0.62 tCO2eq./t. The explanation is that only part of the RCF supply replaces alternative materials, while the rest merely increases overall textile supply and thereby the overall fossil emissions.

Conclusions: Due to imperfect substitution, the increased supply of bio-based textile fibers may increase both biogenic and fossil emissions and both in the short-run and in the long-run. The result highlights the need for empirically assessing market dynamics to support consequential LCA. It further points to the difficulty of decoupling the environmental footprint of the textile sector from the growing consumption by substitution alone.

3.02.B.T-07 Sharing the Carbon Budget Among Human Activities Based on Consumption Patterns of Exemplary Countries

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Absolute environmental sustainability assessment involves allocating carrying capacities among different human activities, products and systems. However, existing methods for carrying capacity allocation do not explicitly consider the extent to which an activity is essential for meeting human needs. This study seeks to develop a new approach for distributing the global remaining carbon budget between consumption categories in the period 2020-2050 that is based on the current consumption pattern in countries with relatively low environmental impacts and relatively good living conditions.

First, the exemplarity of all the world's countries was assessed based on environmental and social criteria in several steps. Calculations of footprints (in tCO2-eq/cap) are first done following a consumption-based approach (n = 186). The countries' per capita footprints are then compared to a threshold compatible with the 2-degree target. For the countries under this threshold (n = 80), their exemplarity grade is calculated, which is an average score within 12 social and 6 environmental indicators.

Next, the 5 countries with the highest exemplarity grade were used as models for the distribution of carbon budget between five consumption categories: food, dwelling, mobility, consumption goods, and health and service. The share of current emissions from each consumption category was calculated, and the average share across the five countries was calculated for each consumption category. These average shares were then used to develop a linear transition from today's global emissions distribution to the exemplary budget distribution in 2050. Finally, to provide absolute budgets, this percentage distribution was multiplied by the yearly carbon budget compatible with the 2-degree target, as defined by the IPCC until 2050.

The 5 selected countries identified are Moldova, Tunisia, Salvador, Sri Lanka, and Vietnam. To follow the average distribution of those countries, the global share of emissions from dwelling and food should, on average, increase while it should decrease for the three other categories. These results indicate that consumption patterns that are both consistent with climate targets and the meeting of human needs may be significantly different than consumption patterns in most countries today. Large disparities are, however, observed for the composition of current consumption-based emissions among the exemplary countries: this could mean that there is not one way to achieve a low-carbon lifestyle.

3.02.B.T-08 Responsibility of Consumption for the Aquatic Species Loss Through Induced Water Consumption in Global Supply Chains – Case of Japan

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In this work, we demonstrate how our final consumption activities remotely induce water consumption and associated impacts on biodiversity in the global supply chains. Freshwater consumption results in the potential loss of around 16 out of 11,450 river fish species per year globally. Japanese final demand is responsible for around 1.2% of the total water consumption in the world, while 0.2 river fish species (2% of the global total loss) could be lost by Japan-induced water consumption. Countries with high biodiversity loss potentials are different in the context of either global or Japanese-induced, which highlights that Japan has the relatively higher responsibility for the potential loss of biodiversity in Australia, South Africa, and China, whereas Turkey, Spain, United States, and Mexico are the most affected countries in the global context. Visualization of hidden responsibility of water consumption in global supply chains will contribute to make a strategy for global biodiversity conservations.

3.02.B.T-09 The Route to Paris in the Swedish Backcountry: Development and Application of a Life Cycle Assessment Method to Assess Sufficiency Measures

Hampus André, KTH Royal Institute of Technology; Anna Björklund, KTH Royal Institute of Technology.

Reaching environmental sustainability, e.g. the targets of the Paris agreement, requires both efficiency measures, which reduce impact per functionality of a product, and sufficiency measures, in other words, "getting by with less" or considerably changed functionality. Life cycle assessment (LCA) is currently limited to assessing efficiency measures due to the method's foundational criteria of strict functional equivalence. Since sufficiency measures, by definition, reduce or considerably change the functional output of an alternative, an LCA of a sufficiency measure would require comparing alternatives that are not functionally equivalent in the strict sense and therefore not comparable in today's LCA.

To address this limitation of LCA, this study develops and tests a novel LCA methodology, called Sufficiency-LCA. A key feature of Sufficiency-LCA is that alternatives with similar but non-equal functional output can be regarded as functionally equivalent through the use of, at least, two functional unit definitions. In addition to environmental impacts, actors that consider implementing sufficiency measures require knowledge on how such measures may change the function of their products and services, since this could determine their feasibility. Hence, another key feature of the method is quantification of the change in functional output resulting from the sufficiency measure.

The study follows the climate transition of the Swedish Tourist Association, an organization offering restaurant and accommodation services in the Swedish backcountry. They consider implementing a range of climate measures, many of which are sufficiency measures, e.g. reducing the use of fresh ingredients in their restaurants, which currently requires helicopter transport during the summer. The sufficiency measures are likely to reduce the functional output of their services. Guest satisfaction is used to measure this potential difference in functional output.

Preliminary results indicate that sufficiency measures can be implemented without severely compromising guest satisfaction. Reducing fresh ingredients is however less effective for reducing climate change impacts than reducing meat and dairy ingredients, while both measures are indicated to cause similar reductions in guest satisfaction.

Providing such results shows that Sufficiency-LCA could be a valuable new method with the potential to strengthen the relevancy of LCA in the pursuit of environmental sustainability.

3.02.B.T-10 The Environmental Impacts of Current Belgian Diets
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Background and purpose: There is a growing concern about the various impacts of food consumption, both on the environment and on public health. Evaluating these impacts at the national level is crucial for the implementation of proactive policy measures. This research aims to assess the environmental impact of the current Belgian diets, with particular attention to the role of ultra-processed foods (UPF) and protein type. This research is part of the SUSFOODBEL project, which seek to identify priority policies affecting the food environment in Belgium in order to facilitate the transition towards more sustainable diets.

Methods: The methodology consists of three key stages. Firstly, the Belgian diet was summarised, based on data from the most recent Belgian National Food Consumption Survey (2014-2015). Secondly, the origin of the most frequently consumed foods was traced using trade databases, such as FAOstat. Finally, a cradle-to-grave life cycle assessment was carried out to determine the environmental impact of those foods. The assessment was carried out using the Agribalyse 3 database and included the impact categories of climate change, land use, water use and fossil resource use.

Results: The results indicate greenhouse gas (GHG) emissions of 4.4 [4.27 – 4.54] kg CO2 equivalent per person per day, which is more than twice the threshold set by the EAT Lancet report. Red meat and poultry, along with beverages, dairy products, and snacks, are the primary contributors to GHG emissions. Similar results were observed for land use. Water use and fossil resource use exhibited different trends, with beverages being the most impactful food group. Moreover, UPF account for 50% of the total climate change and land use impacts, with a linear relationship observed between increased UPF consumption quintile and GHG emissions and land usage. A similar linear trend is observed in the relationship between the ratio of animal-to-plant protein intake and climate change and land use impact categories.

Conclusion: This study highlights the importance of implementing measures to mitigate the environmental impacts associated with Belgian diets in order to adhere to planetary boundaries. Furthermore, it emphasises the need for targeting the consumption of high impact foods such as UPF and animal-based products. Future research will investigate the relationship between environmental and health impacts.

3.02.P - LCA and Sustainable Consumption

3.02.P-Tu032 Life Cycle Assessment of Chicken Co-product Valorisation in the UK
Yiming Sui, University of Reading; Eugene Mohareb, University of Reading; Stefán Thor Smith, University of Reading.

As the global population increases and food systems advance, food loss and waste (FLW) have become significant issues that negatively impact the global environment. However, so far there is no objective definition of FLW that comprehensively covers all types of FLW. For instance, in the UK, chicken co-products, such as feet, giblets, and other offal are often considered as waste and are sent for valorisation rather than being consumed as food. However, a large number of chicken co-product being produced annually, and there has still been limited research focusing on the environmental impact of chicken co-products, or assessment of the subsequent chicken co-product valorisation process in the UK.

This paper conducts an LCA on 1 tonne of chicken co-products in the UK to compare the environmental impacts of 5 scenarios and uses sensitivity analysis to determine the influence of avoided products from system expansion on the assessment. The study illustrates that in scenario 1 - where all chicken co-products are produced into petfood - is identified as the most environmentally friendly option, whereas scenario 3 - where all chicken co-products are disposed of by incineration - generates the largest environmental impacts. Sensitivity analysis shows that the choice of avoid products could significantly influence LCA outcomes and avoiding the use of a feed product combination of soybean meal + palm oil provides the lowest environmental impacts. However, the endpoint score of pet food scenario is only 5.21 points lower than baseline, suggesting that more rational and environmentally friendly options for processing chicken co-products may still be explored.

3.02.P-Tu033 Toward Adequate Nutrition: Exploring the Environmental and Nutritional Characteristics of Belgian Diets
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Unhealthy dietary habits and environmental consequences of food provisioning are leading global risks. While numerous studies have explored the nutritional and environmental aspects of food consumption, there has been limited focus on examining the effects of adjusting individual dietary intake within diverse diets. This study addresses how much Belgian dietary habits (n=862), split into an omnivorous, a pescovegetarian, a vegetarian, and a vegan diet, nutritionally and environmentally improve/decline when they are nutritionally optimized.

Belgian dietary habits were retrieved from a food frequency questionnaire by Clarys et al. (2014), excluding dietary supplements (baseline case). A nutritional assessment was conducted that included the alignment with guidelines (considering supplement intake for restricted diets) and the calculation of the Alternative Healthy Eating Index (AHEI)-2010. Dietary patterns not meeting the guidelines were adjusted accordingly using a quadratic programming algorithm. A cradle-to-grave LCA was performed with the functional unit "daily food and supplement intake by one Belgian adult". The method was Environmental Footprint 3.0, and the impact categories were carbon footprint (CF) and water use (WU).

The largest average AHEI (24%) and CF (as kg CO2 eq) improvements (-27%) were achieved by optimizing the omnivorous diet, whereas the average WU (in m^3) increased the most of all diets (49%). This observation of the AHEI and CF is mainly due to the reduction in red meat intake and the one of WU due to the rising fruit intake. The three restrictive diets demonstrated improved nutrition and worsening environmental profile, with an AHEI increase of 17% for vegetarians and vegans, mainly due to omega-3 supplement intake. The increase for pescovegetarians was rather limited (4%) since the average baseline diet scored already well. The rise in the CF was 15% for vegetarians, 12% for pescovegetarians, and 6% for vegans. This was mainly due to heightened consumption of dairy for (pesco)vegetarians, while legumes, nuts and seed for vegans. The WU raised 39% for pescovegetarians, 35% for vegetarians, and 30% for vegans, the reason being similar as for the omnivorous diet and also an increased consumption of almond nuts for the vegan diet.

This research highlights that improving nutrition worsens mostly the average environmental performance and demonstrates the importance of assessing multiple environmental indicators.

3.02.P-Tu034 A Systematic Approach To Evaluate Uncertainties in Absolute Environmental Sustainability Assessment

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Evaluating the environmental impacts of products and systems in absolute environmental sustainability assessment (AESA) introduces new sources of uncertainties related to the quantification and downscaling of carrying capacities. The selection of sharing principles to guide the downscaling of carrying capacities has been identified as a dominant source of uncertainty in AESA outcomes. However, there is currently no method to quantify this uncertainty alongside other sources of uncertainty also affecting AESA outcomes, such as parameter uncertainty in the life-cycle inventory data. This work presents a new framework to quantify these uncertainties under a unified approach. The framework considers 19 downscaling methods as a result of a systematic review of AESA studies. These methods are grounded on five different sharing principles and seven different enacting metrics, such as gross value added. The followed probabilistic approach compares the range of downscaled carrying capacities to the range of LCA impact scores, allowing practitioners to avoid the value-based choice of sharing principles and enacting metrics. Applying the framework to the French electricity production mix indicates that LCA impact scores were significantly higher (i.e., >95% of the Monte Carlo simulation runs) than the downscaled carrying capacities in seven out of ten planetary boundaries. For some of these planetary boundaries, a limited share of runs respected the downscaled carrying capacity, indicating that certain combinations of foreground LCI parameter values, carrying capacity values, and downscaling methods lead to compliance. For instance, 21% of the runs were compliant for change in biosphere integrity, corresponding to a median LCA impact score with a 90% uncertainty interval equal to 0.0081 (0.0047-0.012) % of biodiversity intactness index (BII) loss, as compared to a downscaled carrying capacity equal to 0.0032 (0.00034-0.017) % BII loss. When compared to dominant downscaling methods in the literature, the UNCASE framework demonstrates that addressing uncertainties is needed for achieving more robust outcomes concerning the environmental performance of the assessed sector, leading to better-informed environmental targets.

3.02.P-Tu035 Insects, a Sustainable Animal Feed?

Emily Dawson, Ricardo; Sam Hinton, Ricardo; Fei Zhang, Ricardo; Jack Salmon, Ricardo; Dave Freeman, Ricardo; Liam R Rock, Ricardo; Felicity Crotty Rock, Ricardo.

1. Challenge

Meat production is a significant source of global emissions, accounting for up to 20% of global greenhouse gas (GHG) emissions. For pig and poultry, which account for 76% of current meat production, over 60% of the meat's lifecycle emissions arise from the production of the animal feed. Efforts to reduce the emissions from meat production must therefore consider animal feed. Moreover, many protein sources have wider sustainability issues beyond GHG emissions associated with their production such as deforestation, biodiversity loss or unsustainable marine harvests.

Insect protein is promoted as a potential solution to the above problems and is often suggested as a sustainable protein source that can be used to reduce the impacts of animal feed. However, insect protein in pig and poultry animal feed is not currently allowed in the UK and before making any decisions on whether to allow this, the UK government needs a way to robustly quantify the sustainability impact of insect protein compared to conventional alternatives. This is where life cycle assessment (LCA) can help.

2. Solution

The UK government's, Department for Environment, Food & Rural Affairs (Defra) appointed Ricardo to conduct an LCA of the potential environmental impacts of insect meal produced in the UK compared to more conventional animal feeds of soybean and fish meal. The LCA was modelled in SimaPro 9.5 using ecoinvent v3.9.1 database to assess the 16 environmental impacts as contained in the EF3.1 LCIA methodology.

3. Outcome

The LCA enables Defra to understand the sustainability impacts associated with different protein sources and shows that as an animal feed, insect protein may not be the sustainable solution that it is positioned as. However, if produced under the correct conditions it can offer the potential to decarbonise animal feed if used to replace higher impact proteins.

This study demonstrated that LCA is an important tool for supporting sustainable decision making by policy makers. The LCA provided Defra with information on where further research is needed and highlighted that while insect protein does have the potential to reduce animal feed's impacts, this is dependent on production conditions and the feedstocks used. Insect protein is not the golden solution to the problem.

3.02.P-Tu036 Novel Sustainable Food Profiling Model to Evaluate the Absolute Environmental Sustainability of Foods While Considering Nutritional Quality

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Background and Purpose

Numerous studies show that shifting towards low-emission diets can reduce the environmental impact of food systems while ensuring adequate nutrition, and the issue of keeping global food consumption within the safe operating space (SOS) (i.e., planetary boundaries) has been addressed in the EAT-Lancet Commission's framework for a planetary healthy diet. However, nutritionally adequate and environmentally sustainable food consumption and production can include a wide selection of foods, which requires detailed information on individual food products. Also, from industry and consumer perspectives, product-specific information is often more useful than diet-level results. To evaluate product-level information, we introduce Nutrient Index-based Sustainable Food Profiling Model (NI-SFPM), a novel approach that combines environmental and nutritional aspects to evaluate the sustainability of food products and profile them as sustainable or unsustainable against the assigned share of SOS (SoSOS).

Methods

The NI-SFPM combines the methodological approaches of nutritional life cycle assessment (nLCA) and planetary boundary-based life cycle assessment (PB-LCA). The model compares the nutrient composition of food products against the daily recommended intakes and the environmental impacts against the SoSOS of products based on the nutrition provided. To showcase the NI-SFPM's applicability, an assessment of 559 food products across various categories was conducted by applying product-group specific nutritional functional units and evaluating the SoSOS offood systems based on the nutritional functional units. The food product selection and nutrient composition were derived from the Food Composition Database Fineli®, and environmental impacts from the Agribalyse database.

Results

The results demonstrate the model's effectiveness in differentiating food products and food categories based on their environmental and nutritional sustainability performance. The model promotes for example many vegetables, whole grain foods, legumes, and some fish, as sustainable food products, which aligns with recommendations given in several diet-level studies.

Conclusions

By evaluating the sustainability of food products, the NI-SFPM enables informed decision-making for consumers, policymakers, and food industry stakeholders. Moreover, the NI-SFPM identifies areas for improvement in both environmental and nutritional aspects, thereby assisting in optimising production processes, sourcing sustainable ingredients, and enhancing product formulations.

3.02.P-Tu037 Assessing the Environmental Impact of Faba Bean Tofu: Consequences of Introducing a Legume-Based Protein Alternative in the Swedish Agri-Food System

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Background and Purpose

A shift towards a more plant-based diet in Western societies has been proposed to reduce the environmental burden of the agri-food system and address health problems associated with excessive meat consumption. To facilitate this transition, it is important to present protein alternatives in a more palatable manner. One innovation is the tofu variant being developed at the Swedish University of Agricultural Sciences using Swedish faba beans. This study explores the environmental impact of the innovative product and compare it with other protein food alternatives. We also assess the effects on the Swedish agri-food system of expanding faba bean cultivation in different regions and under different scenarios.

Methods

The environmental impact of the faba bean tofu is quantified using attributional LCA methodology including all the important inputs and outputs throughout the life cycle stages faba bean cultivation, tofu production and waste treatment. In addition to the ALCA, we use a consequential LCA approach that includes, for example, effects on yield of other crops grown on the same land, substitution of meat products, and the effect of the land use change. In the CLCA, we investigate two different strategies for expanding grain legume cultivation: i) substitution of current crop cultivation and ii) reintroduction of agricultural land into practice. Three different regions in Sweden Skåne, Västra Götaland and Uppsala are included to represent different agronomic conditions.

Results and Conclusions

The results show that faba bean tofu has a low environmental impact, especially compared to animal-based products, but also compared to soya bean tofu, which requires longer transport and is often produced in countries with higher emissions from the background system. The CLCA shows that the way in which faba bean tofu is introduced into the agri-food system affects its climate impact. The impact was lower when unused fallow land was used for faba bean cultivation. However, both scenarios showed high mitigation potential when including the substitution meat products.

Overall, the study highlights the potential to reduce the environmental impact of the agri-food sector by expanding grain legume production. The ALCA results can be useful for environmental labelling and for comparison with other protein-rich foods, for example in procurement. However, the ALCA results do not capture the systemic consequences of the expansion of faba bean production in the Swedish agri-food system, which are better captured by the CLCA results.

3.02.P-Tu038 Climate Impact Dataset to Promote Sustainability of Food Service Operators in Finland – Learnings From Dataset Creation

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Background and Purpose

The food service and restaurant industry play a pivotal role in promoting sustainable food consumption through offering sustainable meal options and shaping consumers' preferences. This study aims to contribute to these efforts by generating generic, ingredient-level carbon footprint data tailored to the needs of the food service sector, supporting the industry's long-term carbon neutrality objectives. Furthermore, our project aims to facilitate the integration of this carbon footprint data into production control systems used by restaurants, while making it compatible with the Finnish food composition database Fineli, which improves the usability of the data and thus supports food service operators in making sustainable choices in their day-to-day operations.

Methods

The creation of the dataset included five main steps: i) reviewing the existing LCA data on domestic food production, ii) assessing the production of products with no available data and updating the assessments of major food crops, iii) identifying relevant data for the production of imported products from LCA-databases, iv) modelling the processing of agricultural products into ingredients based on the Agribalyse database by altering raw materials and other inputs in the database, and v) deriving the final climate impacts for ingredients by calculating the weighted averages based on the degree of domestic origin. To evaluate the accuracy of processing information in the Agribalyse database in a Finnish context, we compared the results with the ones existing in previous research for processed food products.

The first version of the dataset was then refined in an iterative process, where the dataset was tested by food services and data gaps on ingredients identified by the users were then filled.

Results and discussion

The final dataset covers around 500 most important ingredients used in food services, covering the impacts of the entire production chain of ingredients from primary production to the point of service. The altering of existing database processes with information on Finnish agricultural production and other inputs (e.g., emissions of energy consumed in Finland) proved to be a feasible method for creating the post-farm life cycle for a large set of food products. The benefit of such approach is that it enables turning a relatively narrow set of agricultural products into several different processed food products. The lack of processing data often limits the assessment of food products, and thus impacts covering only the agricultural stage without the post-farm stages are sometimes used, for example in diet-level models. Tailoring the existing databases with context-specific information also holds the potential for more accurate modelling, than directly using existing information from databases.

Conclusions

Creating openly available datasets for food services and ensuring their compatibility with production control systems can support the development of more sustainable operations. This can also promote sustainable food consumption by facilitating more sustainable food selection in restaurants. Efficient utilization of existing databases can reduce the resource intensity in creating such datasets. Also, involving the end users in the development process can enhance the

3.02.P-Tu039 Addressing Nutrition in Functional Unit for Food LCA

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Background and Purpose. In food LCA, it has been typical to use mass-based functional units (FU) although they do not address any functions of food products (may) have, particularly from consumer's perspective. Nutrient indices, composed of several nutrients and initially designed to nutrition education for promoting healthy diets, have recently proposed to be utilized as nutritional FUs (nFUs) to address a general nutritional function of foods. We have developed a product-group-specific approach, instead of a general index, to include nutritional aspects in FU.

Methods. To establish nFUs for various product groups, we adopted a product group-specific approach based on the "plate model," designed to guide consumers in creating healthy meals and promote the healthy diet. This allows to categorise products according to their intended use. Accordingly, four product groups were identified: protein sources, carbohydrate sources, a group consisting of vegetables, fruits or berries, and meal drinks. As the selection of nutrients for the index is always closely related to the dietary context in which the results are to be utilised, the approach we applied in two different dietary contexts, first the Finnish, and then the Spanish. Developed nFUs were tested through assessments of typical foods in the regions. For the Finnish case, different nutrient selection strategies were evaluated and a validation study to evaluate the suitability of the strategies for the baseline use that refers to the current dietary situation was conducted using principal component analysis.

Results. Nutrient selection strategy based on the population's current food consumption, identifying key nutrient sources within each product group, was considered the most representative to capture the nutritional function of each group. Indices based on this strategy, called the baseline indices, were selected as recommended for a general use. The food grouping and the choice of nutrients resulting in the baseline index were largely supported by the validation study, although some changes in the nutrient selection could be suggested. The baseline indices, adapted to Finland and Spain, led to differences in the sets of nutrients included in the indices. This highlights the differences in food cultures, which should be considered in the assessment when producing information to support changing food consumption. The baseline indices use as nFUs in the test calculations balanced differences between protein source foods, for example, but on the other hand made preferable difference between wholegrain and refined products.

Conclusions. The study revealed the usability and value of the product group-specific nutrient indices as nFU. The product-group-specific approach can be systematically applied to formulate nFU indices that consistently represent the nutritional function of different product groups.

3.02.P-Tu040 Does Utilizing Fish Sludge as Biofertilizer Reduce Pressure on Planetary Boundaries? - A Case Study

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Background and purpose: Food production heavily relies on mineral fertilisers like phosphorus (P) and nitrogen (N) to achieve high yields. However, their use often leads to negative environmental impacts such as soil degradation, biodiversity loss, and eutrophication due to leakage. To mitigate these effects, efficient nutrient recycling is needed. Anaerobic digestion (AD) of biodegradable byproducts like food waste and fish sludge, which produces digestate that can replace traditional fertilisers, is a promising way forward. This approach can enhance sustainable nutrient cycling if managed responsibly, ensuring it does not exceed environmental limits or increase pressure on planetary boundaries. In Norway, the use of food waste in AD is growing, with fish sludge being a significant potential feedstock for biogas. This study aims to evaluate the environmental benefits and reduced planetary boundary (PB) pressures of using digestate from mixed food waste and animal manure, as well as mixes containing fish sludge, instead of mineral fertilizers.

Methods:Three products were evaluated with Life Cycle Assessment (LCA) and PB-LCIA methodology: 1) mineral fertiliser, 2) digestate from food waste and animal manure, 3) digestate from animal manure and fish sludge. The functional unit was defined as 1 kg of mineral fertiliser or digestate spread on crop land adjusted for N and P content. The share of the planet's safe operating space (SOS) that fertiliser use in Norway can have, will be assessed and the method will be evaluated and discussed. A sensitivity analysis was performed to evaluate the effect of allocation between biogas and digestate at the AD plant and ratio of plant available N and P was also changed to evaluate impact of amount of mineral N that could be substituted. Finally, the influence of transport distances was evaluated.

Results: The preliminary results from performing the LCIA on the three products showed both types of digestate to have lower environmental impact for all 16 impact categories compared to mineral fertiliser use. The PB-LCIA displayed similar tendencies.

Conclusions: The study implies that if digestate substitutes mineral fertiliser, nutrient circularity can be improved, and environmental burdens can be reduced. The understanding of the local and global impacts of nutrient management practices is crucial for making informed decisions.

3.02.P-Tu041 Global Environmental Impacts of Hidden Flows Generated From China's Passenger Car Production

Binze Wang, Tohoku University; Qiance Liu, University of Southern Denmark; Kazuyo Matsubae, Tohoku University.

Electric mobility (e-mobility) is vital for reducing greenhouse gas emissions but poses significant environmental challenges due to intensified mineral extraction, resulting in substantial hidden flows, including topsoil overburden, waste rock, and tailings. These hidden flows can generate environmental impacts such as soil contamination, groundwater pollution, and biodiversity loss. Although the quantities generated from the sustainable mobility transition have been quantified, their impacts are poorly understood. Our study distinguished the hidden flows by mineral type, sulfidic/non-sulfidic mine type, and country type, and estimated the global impacts of hidden flows caused by China's passenger car production using life cycle assessment.

The results show that the potential impact on human health and ecosystem quality in China was 261,931.05 DALYs and 194.62 species.yr in 2019, respectively. In addition to domestic resources, China also imports minerals from other countries, generating impacts in those resource-supplying regions. Chile, Peru, and Australia are the top three countries bearing risk responsibility for China's vehicle production. For example, Chile bore 30 DALYs and 0.02 species.yr in 2019, primarily due to copper mining to support China's vehicle production. These results underscore that the global community has borne and will continue to bear a growing environmental cost for China's sustainable e-mobility transition, highlighting the imperative for a collaborative global effort to manage the degradation of natural assets.

3.02.P-Tu042 Integrating System Perspectives in Sustainability Assessments of Digital Health Devices: A Case Study on Digital Display Label in Clinical Trials

Erasmo Cadena, Ghent University; Lieselot Boone, Ghent University; Jo Dewulf, Ghent University.

Background and purpose:

The technological revolution has had a profound impact on numerous sectors, including healthcare. The adoption of digital health devices has increased rapidly, reflecting their potential as alternatives to traditional healthcare equipment. These innovative devices provide reliable diagnostics, enhanced self-monitoring capabilities, improve patient comfort, and promote less invasive medical procedures. However, despite these considerable advantages, the overall understanding of their sustainability impacts remains incomplete. This gap highlights the need for further research into the environmental, economic, and social impacts associated with the widespread use of these devices. The Horizon Europe project, Digital Health in the Circular Economy (DiCE, grant agreement: 101060184), aims to address this by developing circular and eco-friendly solutions for various digital devices, including digital display labels (DDLs).

Methods:

In the DiCE project, a system perspective approach is adopted to evaluate the sustainability of clinical trials of a particular drug product. The functional unit defined was "100 patients having administered one dose of a particular drug at the clinical site delivered by properly labeled packaging." This provides a clear and measurable basis for comparing the sustainability of different labeling methods. The scenarios to be analyzed include the clinical supply chain using: (i) conventional label and (ii) the newly developed DDL.

Results:

Initial data suggest that the use of DDLs can significantly reduce waste and unused supplies, potentially leading to a notable decrease in the carbon footprint associated with pharmaceutical products in clinical trials. DDLs offer substantial advantages over traditional paper labels by improving efficiency, compliance, patient safety, and adaptability in clinical settings. This approach aligns with the growing necessity to modernize clinical supply chains through digitization, addressing challenges such as limited label space and the need for flexible information dissemination.

Conclusion:

The case study within the DiCE project illustrates the necessity of adopting a systems perspective in sustainability assessments, encompassing all stages from device manufacture to end-of-life, as well as the indirect benefits arising from improved healthcare procedures. This broader perspective is essential to truly understand and enhance the sustainability of digital health solutions within the healthcare sector.

Acknowledgments:

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3.02.P-Tu043 Are We Trading Lightweight Airframes for Climate Change?

Su Natasha Mohamad, University of Sheffield; Rachael H. Rothman, University of Sheffield; Anthony J. Ryan, University of Sheffield.

Modern aircraft manufacturing extensively employs polymers and plastic composites to construct lightweight airframes that still deliver robust performance. These plastics are selected for their outstanding properties, such as high resistance to corrosion and fatigue, which are particularly beneficial under severe environmental conditions. Fibre-reinforced plastics (FRP) are capable of withstanding numerous loading cycles without failure, thanks to their excellent fatigue resistance, offering an effective strategy for reducing fuel consumption. However, what is the environmental cost? The diverse range of composites complicates the segregation and recycling processes at the end of an aircraft's service life. This results in a heterogeneous mix of plastic waste, leading to prevalent disposal methods such as landfill use. The blend of complex plastics and composites presents a significant challenge in achieving a sustainable end-of-life pathway for these materials and fostering a circular economy. To understand this issue, the study examines a few scenarios to observe how circular thinking could be the answer we seek. Aircraft cabin interiors are characterized using Fourier-Transform Infrared Spectroscopy, and polymers such as polyetherimide, polycarbonate, nylon, polyvinyl chloride, silicone rubber, polymethyl-methacrylate, and polysulfone were identified. An LCA is performed from cradle to gate and followed by three end-of-life scenarios considered: (i) frequency of replacements during the use phase, (ii) renewable energy use, and (iii) recycling potential. Findings highlighted that FRP contributed the most significant impacts (including acidification, climate change, eutrophication, etc.) among all types of polymers, and the percentage of recycled content should be more than 40% for a more positive environmental return. This project is essential to allow us to design a cleaner and more sustainable exit for aircraft cabin interiors

3.02.P-Tu044 Environmental Impacts of Alternative Reductant in UK Blast Furnace Ironmaking

Siti Ahmad, University of Sheffield; Richard Thackray, University of Sheffield; Peter Hodgson, Tata Steel UK; Marta Cruz Fernandez, Tata Steel UK; Peter Holliman, University of Swansea; Rachael Rothman, University of Sheffield.

This study investigates a novel approach to decarbonize steel production, a sector accounting for 8% of global CO2 emissions (2023 data). In line with the Paris Agreement's net-zero target by 2050, the research explores the complete replacement of coke with charcoal as a reductant in UK blast furnace ironmaking. Life cycle assessment (LCA) methodology is employed using SimaPro software to compare the environmental impacts of conventional coke and a potential charcoal-based alternative.

The findings demonstrate significant environmental advantages associated with charcoal. Global Warming Potential (GWP) and Fossil Resource Scarcity (FRS) are reduced by 32% and 58%, respectively. However, a key challenge identified is the increased land use (LU) of 258% for charcoal production compared to coke. The study proposes sustainable practices such as utilising degraded land (abandoned mines) or implementing intensive plantations of fast-growing biomass crops to mitigate this impact.

Furthermore, a sensitivity analysis reveals that transportation plays a critical role in the environmental footprint of coke-based ironmaking. Optimising the supply chain, particularly through sourcing from closer locations, has the potential for significant environmental improvements. Building upon these findings, future research will investigate additional promising alternative reductants such as e-coke and hydrogen. The aim is to integrate environmental assessments with efficiency and economic evaluations, ensuring scientifically robust and practically implementable solutions for the steel industry.

3.02.P-Tu045 Enhancing Food Consumption-based LCA Accuracy Through Regionalization: A Case Study of the French Riviera's Highly Imported Diets

Andrea Lulovicova, Université Côte d'Azur; Stephane Bouissou, Université Côte d'Azur.

Food consumption is a critical hotspot in consumption-based LCA studies. Globalization of food supply chains can lead to carbon leakage under territorial carbon accounting. This study aims to assess the climate change potential and water scarcity impacts of diets in the Alpes-Maritimes region of the French Riviera, characterized by a high dependency on food imports. The implications of refined inventory regionalization of the food supply chain are explored.

Firstly, the sub-national food-consumption database INCA 3 is downscaled to the regional population to model local diets. Those are further linked to the French Agribalyse LCI database, including country-level data, to assess local diets' impacts and hotspots. Secondly, regional import-export trade data and logistics surveys are used to map food flows of the three traditionally produced commodities: lamb meat, tomato, and olive. Secondary LCAs are conducted for these products using a regionalized inventory based on the geographic coverage of their imports to the studied region and domestic production. The objective is to compare the results of average national-scale and region-specific LCAs to estimate the need for further data regionalization. The ultimate objective is to assess the potential environmental consequences of increased local production of the selected commodities, such as included in the Regional Sustainable Food Strategy. The impact of the regionalization is estimated to vary according to the food product modeled. These findings can consequently guide local authorities in shaping sustainable food supply and consumption policies.

The results can further be compared to locally monitored environmental indicators such as territorial GHG emissions and water use. A considerable gap between the territorial and consumption-based approaches is expected, highlighting the necessity of implementing consumption-based assessments alongside territorial accounting in the agriculture and food sector. This is particularly relevant as regions are increasingly at the forefront of implementing environmental policies, such as France's net-zero carbon strategy. Yet, the study underscores the complexity of integrating these approaches due to challenges in mapping both international and inter-regional food supply. Finally, the study emphasizes the need for more regional LCIs, as the lack of country and region-specific inventories for background data remains a major limitation in streamlining regionalized LCAs.

3.02.P-Tu046 Navigating Consumption Dynamics through Consequential Life Cycle Assessment of Fish Products

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Wild fish stocks are crucial for global food supply. Although fishing is relatively climate-friendly, it still contributes significantly to emissions due to fuel use. Carbon footprint studies help understand the environmental impact of fish products and practices. While traditional studies use an attributional approach, consequential LCA uses a consumption perspective, estimating the impact of changes in demand by identifying affected suppliers. As fisheries are based on a very limited it's vital to identify suppliers that can meet the increased demand. This research aims to identify these unconstrained suppliers for fish products and address the research gap in consequential modelling of fish products.

The hypothesis is that only unconstrained suppliers will respond to increased demand for fish. If no fishery meets this demand, substitution with equivalent products may occur. The study uses Danish national landings and quota data to assess marine capture fisheries' production potential. For fish products that do not have unconstrained suppliers, distinct criteria are used to define the marginal mixes. These criteria are classified as nutritional values, price, and cultural function reflecting the nutritional content, comparative price and the role of specific fish products in the food chain.

Preliminary results show that Denish major commercial species cannot potentially sustain increased demand due to declining trends. The expected result is a model depicting a diversified market mix of suppliers. This mix can include aquaculture products if substitution is based on nutritional content, or a blend of animal and vegetable proteins if driven by price or cultural functionality. These market mixes are then applicable in consequential LCAs of fish products.

The analysis highlights the impact of increasing fish demand and identifies sectors potentially affected by displaced demand. The consequential approach focuses on future consumption consequences, guiding consumers towards sustainable choices. Policymakers can use the results to develop dietary guidelines that promote health and environmental sustainability.

3.02.P-Tu047 Towards Sustainable Protein Consumption: Life Cycle Assessment of Cell Banking For Cultured Meat Production

Maria Ignacia Rodriguez, Ghent University; Erasmo Cadena, Ghent University ; Jo Dewulf, Ghent University.

Background and purpose

As the demand for sustainable food production intensifies, cultured meat has emerged as a promising alternative to traditional livestock farming. This study presents a life cycle assessment (LCA) of the cell banking process specific to cultured meat applications.

The goal and scope of the assessment is to quantify the environmental impacts from cradle to gate, from cell collection to the cryopreservation of the final product, in order to produce 1 kg of cultured meat (wet weight). Key indicators such as climate change, land use, water use and others are evaluated and provide valuable information supporting process optimization.

Materials and methods

Data for the cultured meat production process were collected through collaboration with a leading cultured meat producing company's facilities and operations, focusing primarily on the cell banking stage. Detailed information regarding the cultivation, different media composition, equipment and waste management practices was provided by the company to ensure accuracy and reliability in the assessment.

The LCA was conducted using the SimaPro software, in which supporting processes and flows were modelled by the Ecoinvent 3.9 database. The impacts were quantified using the Environmental Footprint impact assessment method. Assumptions, limitations, and data sources were explicitly documented to facilitate reproducibility and robustness of the findings.

Results

The analysis revealed that the environmental footprint associated with the cell banking stage of cultured meat production was remarkably low, contributing less than 1% to the total environmental impacts of the process. This finding underscores the relatively minor environmental burden of cell banking compared to other stages of the production process. Consequently, the study suggests that optimization efforts should prioritize enhancing the sustainability of bioreactor operations, media composition and use.

Conclusion

In the road towards sustainable production and consumption, cultured meat has been hailed as an excellent alternative to conventional meats. However, environmental studies, including the one presented, have shown that optimization in certain areas are necessary to enhance sustainability and provide a competitive option to the existing meat replacements.

3.02.P-Tu048 Life Cycle Assessment of agri-food waste utilization– case study example of lemon waste enzymatic extraction

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Background and Purpose: In agricultural food production, large share of fruits and vegetables are discarded, though they could be used as natural additives for food, nutraceutical, and cosmetic applications. The EU-project Agro2Circular uses emerging methods to demonstrate the upcycling of most representative agri-food wastes in Southern Europe (i.e. apple, grape, lemon, broccoli, cauliflower, and artichoke). One of the most potential innovation cases in the project is lemon waste enzymatic extraction where the solid phase is produced into nutritional fibre and the liquid phase into phenolic extracts.

Methods: The dietary fibres and phenolic substances in lemon waste, derived with enzymatic extraction, can replace commercial additives in enriched juices and jams, vegetable desserts, nutraceutical formulations, or cosmetics. The environmental impacts of these new business-to-business products are studied with Life Cycle Assessment (LCA) method (ISO 14040) and modeled with cradle-to-gate system boundary, excluding the use stage. The LCA model considers 50 kg of lemon residues processed with enzymatic extraction, turning into two products, dehydrated solid extract/fibre extract (3,6 kg) and dehydrated liquid extract / phenolic extract (0,6 kg). The environmental impacts are studied with the impact assessment method proposed by European Commission, the Environmental Footprint 3.1 (EF 3.1). The aim is to compare the extracts to products of similar functionalities, for example fibre extract to inulin, and phenolic extract to quercetin, but since the research of the agri-food utilization is still ongoing, the reference products are not confirmed.

Results: The study shows the estimated possibilities of the solution and discusses the biggest potential impacts in the studied life cycle. The most climate impacts (in kg CO_2e) are created with the processes consuming the most energy, primarily the drying processes and secondarily the heating of enzymatic extraction.

Conclusions: Waste from traditional lemon processing can be upcycled into valuable products with enzymatic extraction, producing ingredients for food, nutraceuticals and cosmetics, such as a fibres or phenolic extracts. Based on the LCA calculations, most environmental impacts are caused from drying processes energy consumption.

3.03 - Qualitative Life Cycle Studies Exploring the Practical Meaning of Life Cycle Studies

3.03.A.T-01 LCAs role in Defining the Sustainability of Aluminium

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Driven both by regulatory and by market factors, recent years have seen an explosion of interest in calculating, reporting and reducing environmental impacts in the aluminium industry. Such interest has largely focused on climate change. Both metrics of environmental performance in the aluminium industry and how they are calculated are heavily influenced by arguably non-objective, non-scientific decisions developed and negotiated between science, industry, business, the political realm, and the public. Through illustrative examples of recycling issues, climate change metrics, and the broader environmental impacts of aluminium, we discuss what environmental sustainability might encompass and how it is defined for the industrial sector.

The study is a meta analysis of several LCA and EPD projects performed for production of primary and secondary aluminium. Examples were generated through discussions with industry experts where LCA method choices contribute to define the sustainability of practices.

The first example includes recycling of aluminium and the choice to allocate burdens or not to pre-consumer scrap. The second shows the choice of system boundaries and how benchmarks might be random numbers. The third example will investigate the choice of environmental metrics using the planetary boundaries concept.

The three examples only encompass the aluminium sector itself. In practice, aluminium is competing with other materials for fulfilling functions and the (relative) sustainability of aluminium is also heavily dependent on the analogous non-scientific issues in other material sectors. To judge whether a function should be performed to be aligned with sustainable development would require quite different frameworks than just environmental LCA itself. There is nonetheless an obvious temptation for non-specialist actors to draw simplistic, maybe inaccurate, conclusions from LCA studies that are as nuanced and as uncertain as the examples show. LCA practitioners must be aware of their power and how their choices and the results thereof may be taken as absolute truths.

The paper highlights the entanglement of LCA methodological discussions with the strategic directions and imperatives of the aluminium producer. Furthermore, a focus on single companies or sectors does not give an indication of a sustainable level of production. The pathway towards more sustainable practices will need projects that investigate multiple sectors and functions in conjunction.

3.03.A.T-02 Use of LCA and LCT Within Technology Development of Carbon Capture, Utilisation and Storage

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Employing life cycle assessment (LCA), particularly prospective LCA, in the early stages of technology development presents certain challenges. Carbon capture, utilisation and storage (CCUS) are emerging technologies that convert carbon dioxide (CO2) into products for storage, and LCA is often used to demonstrate their viability or evaluate process designs. This study draws from the firsthand experiences of LCA practitioners involved in CCUS projects to investigate the knowledge requirements encountered during early technology development.

The research entails using social science methods to analyse LCA practices in two collaborative R&D projects. The projects, DECREASE and PYROCO2, aim to advance CO2 utilisation technologies, with LCA playing a pivotal role in evaluating the environmental benefits and sustainability implications of the proposed solutions. The DECREASE project focuses on generating insoluble carbonate minerals or organic carbonates from industrial byproducts and CO2, while the PYROCO2 project aims to produce acetone from industrial CO2 and green hydrogen.

The findings from the two case studies demonstrate different uses of LCA in the projects at different Technology Readiness Levels (TRL), 3-4 and 4-5 respectively. In the first case study, LCA was employed to improve the project group's understanding of the system's properties, the implications of process design decisions, and the directions of future work. In the second case study, LCA was employed to learn about activities with high impact, the potential to produce acetone with lower impact than conventional methods, implications of process design outcomes, implications of location and the choice of carbon dioxide. In summary, LCA offers diverse applications as a learning tool in R&D projects.

Using "ordinary" quantitative LCA, even prospective LCA, during technology development poses a challenge due to the lack of data and concrete designs in the early stages. Multiple LCA studies are necessary to address various knowledge needs and adapt to the project's development stage. The influence of LCA information on decision-making and project development is heavily influenced by each participant's perspective and openness. In conclusion, different LCA approaches are required depending on the knowledge needed in a project, and there is a need for a shift in perception and better understanding of the context of technology development for more effective LCA studies.

3.03.A.T-03 Practices, Politics, Expectations, and Implications of Environmental Footprinting Initiatives for Food

Michael Martin, IVL Swedish Environmental Research Institute and KTH Royal Institute of Technology; Irina Azimova, IVL Swedish Environmental Research Institute and KTH Royal Institute of Technology.

Recently, many labeling and footprinting schemes have flourished based on life cycle based methods aiming to guide consumers and the public and private sectors toward sustainable practices and purchasing. But what is seen as 'sustainable' has led to an increasing share of criticism on the transparency and comprehensiveness of life cycle-based methods,. With new legislation on the horizon, e.g. the Green Claims Directive (GCD), the use, misuse, data, methods, and communication will become increasingly political. This study has aimed to critically investigate environmental footprinting initiatives at different levels, their influence on markets, industry practices, and the implications for the food sector in Sweden.

Document analyses to study the discourse and narratives on how LCA and sustainability information can support more sustainable food systems were employed. Additionally, with interviews with stakeholders broadly in the food sector and LCA practitioners to understand how, why, and what life cycle-based methods are being used in the food sector and the implications of LCA for the food sector.

Our results suggest that there is a good understanding of LCA in the food sector, though its intricacies are not evident. LCA was seen more as a tool to legitimize sustainability claims primarily for aiding consumers. LCA data was not being used by more than a few retailers and procurers to support more sustainable purchasing decisions, though examples exist, limited primarily to yearly accounting practices. Food producers were also concerned with the growing number of footprinting methods, schemes, and conformity to the GCD, and whether LCA will become mandatory. A recent 'industry-wide' footprinting methodology for food system LCAs has also emerged in Sweden, which was found to be controversial. Furthermore, LCA practitioners suggest that data availability from large LCI database platforms is becoming gradually more controlled and governed to control power in the LCA field. This was found to be counterproductive to promote a more sustainable society. It was found that there are techno-political sites of tension developing across the 'life cycle' of food LCA, from data availability to its use and communication. With further pressure on the use of LCA in the near future in society, especially in the food sector, we will see an increasing political use of LCA and power struggles to legitimize what, and who, decide on what is considered sustainable food.

3.03.A.T-04 Towards a More Effective use of LCA in Industry: a Qualitative Case Study of a Building Product Development Project

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Background and Purpose: This study aims to develop insight into the causal relationship between LCA and decision making. For many years, the LCA community has aimed to use LCA to contribute to better decisions and reduce environmental impacts of the product systems assessed. At SETAC Europe 2024, a fruitful union between good data, better models and sustainable decisions is on the table as well, seemingly implying that better knowledge will lead to better decisions. Despite admirable ambitions, the validity of such a simple and linear causal relationship between LCA and decision making remains unaccounted for and is rarely explicated. As ambitions to use LCA for reducing product environmental impacts are rising – e.g. through the introduction of the EU Taxonomy – a better scientific understanding of the relationship between LCA and decision making is desirable.

Methods: A qualitative case study of a building product-development project has been conducted, with a special focus on its use of LCA. Rather than assuming that LCA results will probably lead to more sustainable decisions, actual events have been analysed where LCA influenced the studied development project. Following an ethnographic research design, data was collected from interviews (32), first-hand observations (18 days), and project documentation (>100 documents). The analytic process followed an empirically grounded research approach.

Results: Based on the case study, seven effect mechanisms have been identified that deviate from a simple linear model of effect: i.e. 1.) a multiplicity of LCA studies and decision moments, 2.) imperfect alignment, 3.) partial effects, 4.) displaced effects, 5.) effects from LCA activities, 6.) heterogeneous actors and activities, and 7.) a two-way directionality of effects between LCA and decision making. In turn, these findings have been synthesized into a more complex linear model of effect and two practice-based models of effect.

Conclusions: This study shows that there is a multitude of ways in which LCA interacts and leads to effects in a decision context, although rarely in a straightforward manner. While the evidence from the case study reveals the existence of several effect mechanisms, it cannot predict the prevalence of these mechanisms across other cases. It is therefore worthwhile to specify the perceived contributions of LCA application on a case-by-case basis.

3.03.A.T-05 Utilization of Life Cycle Assessment (LCA) in Printed Circuit Board (PCB) Recycling – A Bibliometric Analysis Approach

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The escalating generation of Waste Electric and Electronic Equipment and Printed Circuit Boards (PCBs), their fundamental component, has become a pressing environmental concern. Consequently, the need for effective PCB recycling strategies has gathered significant attention. One promising avenue for assessing the environmental impacts of PCB recycling is the integration of Life Cycle Assessment (LCA) methodologies. Therefore, this research aims at evaluating how LCA has been used in this context through a comparative bibliometric analysis. Two distinct search queries, referred to as S1 and S2, were employed to gather relevant literature from Scopus and Web of Science databases. While S1 encompassed a broader scope, S2 specifically targeted publications incorporating LCA methodologies. The resulting dataset, comprising 1644 publications for S1 and 42 for S2, was subjected to thorough analysis using R Studio, Excel Power Query, Bibliometrix R, and VOSViewer. Notably, the analysis revealed a recent surge in the incorporation of LCA into PCB recycling research, particularly intensifying around 2012. A co-occurrence of words analysis suggested that LCA remains a relatively underexplored theme within the broader landscape of PCB recycling literature. However, surrounding subjects were found to be frequently assessed in research that did not involve LCA as a keyword. Moreover, a further analysis into the most relevant authors, countries and journals indicated that they were generally the same for S1 and S2, implying a facility to include LCA in ongoing research. Furthermore, through a citation analysis of the authors, Zhenmin Xu emerged as a prominent figure across both search queries. A further analysis into the author's production identified a trend of incorporating environmental aspects to most of his publications on the specific theme of PCB recycling. Thus, highlighting a direction that could be followed by the other researchers, as LCA becomes a unified methodology for environmental impact assessment within the field. The results suggest that PCB recycling is still an emerging science field, with untapped potential for innovation. Although LCA hasn't been commonly used in this context, the emergence of technologies and information on the PCB recycling could benefit from the incorporation of the LCA methodology into the existing and developing research, enriching the field.

3.03.B.T-06 The Complexity of Achieving Multiple Life Cycles for Long-life Products: A case study of Solar Energy Systems in Kenya and Denmark

Gloria Moscatelli, Technical University of Denmark; Tim McAloone, Technical University of Denmark; Caleb Mireri, Kenyatta University; David Mugendi, University of Nairobi; Anders Damgaard, Technical University of Denmark.

Introduction

The current environmental paradox surrounding solar panel installations highlights the necessity to transition from a linear to a circular model1. This shift requires thorough quantitative assessments, such as Life Cycle Assessment (LCA)2, grounded in comprehensive evaluations of geographical, temporal, and technological contexts. This research compares on-grid and off-grid solar energy systems in Europe and Kenya to answer the following questions: What are the main barriers to the transition to multiple life cycle circularity for these systems? How do these barriers interrelate with each other?

Materials and Methods

Primary data collection through 30+ stakeholder interviews in Kenya and Denmark, focusing on the solar energy life cycle, policies, and socio-economic contexts, forms the basis of this study. Barriers and their correlations are systematically identified and explored across technological, geographical, and temporal scopes. Notably, attention is given to the "second life cycle" of solar components, posing challenges in maintaining material quality over extended periods.

Results and Discussion

The assessment revealed gaps between expectations and reality. Life Cycle Assessment (LCA) often overestimates recycling rates, ignoring real-world constraints and resulting in unrealistic targets. Establishing Extended Producer Responsibility (EPR) for solar energy systems is crucial. Currently, 90% of solar panels and most lithium-ion batteries are produced in China. Enforcing EPR raises dependency concerns, as seen with decommissioned motherboards in Kenya, sent to Dubai and then China for material extraction. Innovation in solar energy systems, driven by design-phase stakeholders, has led to more efficient, cost-effective panels. However, recycling companies struggle to keep up with new designs. As technology evolves, solar panels become obsolete within 15 years, highlighting the need to balance recyclability and durability in design.

Conclusions

To reach sustainability, a departure from the linear economy model is essential. Collaboration among stakeholders, informed by comprehensive assessments, is crucial, with a focus on integrating circularity into processes. Tailored approaches addressing geographical and temporal disparities are necessary, alongside consideration of mid-term and long-term sustainability objectives. Only through holistic and forward-thinking strategies can a sustainable future be achieved.

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3.03.B.T-07 Life Cycle Thinking to Reduce Bread Waste

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Background and purpouse

Food waste reduction calls for systematic change and collaboration across the value chain. Researchers have suggested an "outside the box" Life Cycle Thinking (LCT) approach to address the challenge.

Studies have shown that food value chain actors tend to focus on their own food waste and rarely apply an LCT-perspective when addressing food waste. This paper seeks to shed light on how LCT can play a role in solving the food waste challenge using the bread value chain in Norway as a case study.

The hypothesis is that actors across the bread value chain have different perspectives on how to reduce bread waste, and that bread waste reduction requires an LCT-approach using insights from the whole value chain to avoid sub-optimal solutions and problem shifting. Our study adds to the state of the art by providing empirical insights to this issue within the context of bread waste.

This is research that is currently being undertaken and we can therefore not anticipate the results. The results and discussion will be completed before the conference.

Methods

20 semi-structured interviews with experts across the bread value chain were conducted, aiming to explore bread waste reduction using an LCT-perspective. Each expert was first asked general questions about bread waste, and then presented future scenarios for bread waste reduction.

Results

Based on the experts' insights, the results will aim to present barriers and solutions against bread waste from producer to consumer in Norway. Special emphasis will be placed on evaluating the suitability and LCT potential of the five scenarios for the case of bread.

We expect that the experts have different views regarding bread waste prevention, that may vary based on their position in the value chain and what they are exposed to on a daily basis. Other contributions in the bread waste literature point to packaging optimization, nudges, tools and balancing economic incentives and the power-relationship between the various supply-chain actors as key solutions to reduce bread waste. We will discuss our results in light of this literature.

Conclusions

This study can shed new light on how the perspectives of the actors in the bread value chain are positioned by their roles and whether or how this is related to LCT. The results can be used to inform industry and/or policymakers on how to ensure a holistic approach to bread waste reduction using a life cycle perspective.

3.03.B.T-08 Combining Social Sciences and Life Cycle Assessment - Outlook on Finnish Battery Material Value Chain

Anni Orola, LUT University; Laura Kainiemi, LUT University; Jarkko Levänen, LUT University; Ville Uusitalo, LUT University.

Social life cycle assessment (S-LCA) has its roots in environmental life cycle assessment and natural sciences. However, other disciplines of science, e.g. social sciences, have researched social impacts longer and have more established methods. The aim of this study is to analyze what kind of results can be achieved using a social sciences-based approach and compare it to an approach more widely used in the S-LCA. The study focuses on the emerging Finnish battery material industry. Previous S-LCA research indicates that there are fewer social risks in Finland compared to the largest battery material production countries globally. However, there may be some social acceptability issues regarding the battery material sector in Finland.

Finnish news media articles were analyzed using content analysis to recognize different existing or perceived social sustainability impacts and related actors. Over 70 articles were collected over a period of 6 months using keywords e.g. mining, mine, and battery material. The system boundary included raw material extraction, transportation, and battery material production. Concepts from actor-network-theory with the life cycle thinking framework were combined to shed light on how we can better analyze different stakeholders, actors, and impacts.

Two different types of life cycles were recognized: product life cycle and mine (building) life cycle. Projects still in the environmental impact assessment phase and mineral exploration had the most attention and raised the biggest concerns. Many of these concerns and impacts could be linked to stakeholders and impact subcategories related to Social LCA guidelines but also some new perspectives were revealed. These were e.g., the impacts related to mineral exploration and the role of activists and parent companies as S-LCA stakeholders. The discussion mainly stayed at the national and EU level and the global inequality was not used as an argument to support the acceptability of mining in Finland. Actor-network-theory offers tools on how the different actors related to the battery material life cycle can be further recognized and analyzed.

Actor-network-theory offered knowledge about different viewpoints of various actors in the battery material life cycle in Finland. This study contributes to the discussions about qualitative S-LCA research and what more can we still learn from social sciences to improve the scientific foundation of S-LCA.

3.03.B.T-09 Towards Meaningful Sustainability Assessment: Combining Life Cycle Assessment and Actor-Network Theory for Circular Economy in the Healthcare Sector

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Traditional Life Cycle Assessment (LCA) methodologies primarily focus on quantifiable environmental impacts, often neglecting the socio-technical dynamics such as stakeholder opinions, interactions, and socio-political factors that significantly influence environmental outcomes. Our study aimed to bridge these gaps by integrating LCA with Actor-Network Theory (ANT), providing a novel approach that encompasses the diverse web of relations and influences among stakeholders. This integration is particularly pertinent for addressing challenges associated with the remanufacturing of ultrasound catheters, such as safety concerns, regulatory compliance, new work practices, and the technical feasibility of restoring used devices to their original quality.

The application of LCA integrated with ANT offers a holistic framework for assessing the long-term sustainability of remanufacturing Single Use medical Devices (SUDs), enhancing decision-making processes within the circular economy context. The research utilized a mixed-methods approach, integrating ANT within the traditional LCA framework. Stakeholder interactions were analyzed using ANT's tools, such as translation and network mapping of matters of concern, to assess the different roles and influences of healthcare professionals, regulatory bodies, and manufacturers. Qualitative data from these interactions were integrated with quantitative environmental impact data from LCA. This approach addressed challenges such as reconciling qualitative insights with quantitative data through iterative analysis and cross-validation, ensuring reliability in the integrated methodology.

The application of ANT within the LCA framework highlighted significant discrepancies between perceived and actual environmental impacts in the remanufacturing of ultrasound catheters. Quantitative analysis showed that remanufactured devices could reduce waste and carbon footprint by up to 30%, which contradicted initial stakeholder perceptions that viewed remanufacturing as potentially hazardous and less sustainable. Integrating ANT with LCA not only enhances methodological reliability but also significantly deepens the analysis by incorporating a broader spectrum of socio-technical factors into environmental assessments. This approach has led to the proposal of new theoretical models for sustainable healthcare practices that integrate stakeholder analysis throughout the LCA process.

3.03.B.T-10 In-Depth Assessment of the Need for Life Cycle Competence in Swedish Industry and Authorities

Anna Wikström, Chalmers University of Technology; Yulia Liu, Swedish Life Cycle Center; Maria Rydberg, Swedish Life Cycle Center/Chalmers University of Technology.

The life cycle perspective has gained an increasingly significant role within both industry and society. We are seeing more political instruments and clearer demands from customers where the life cycle perspective plays an important role in driving the transition to a more sustainable consumption and production system.

The project "In-Depth Assessment of the Need for Life Cycle Competence in Swedish Industry and Authorities" is a deepening of a previous project aimed at mapping the industry-identified need for competence to meet these increasing demands, while also maintaining or achieving a leading role in a sustainable society (circular economy, sustainable energy system, sustainable resource use). This project deepens the understanding of these competence needs by looking at, among other things, upcoming legal requirements that include a life cycle perspective and incorporates a larger survey. The project also includes Swedish national authorities, as they will often be responsible for implementing these upcoming legal requirements.

In this presentation, we will present results from a larger survey among industrial companies and authorities where we have mapped the competence needs within the life cycle perspective. We will present results, among other things, on the following areas:
i) motives for working with the life cycle perspective
ii) which existing and upcoming standards, regulations, or policies related to the life cycle perspective are considered relevant for the organizations
iii) how satisfied they are with the use of the life cycle perspective in their organizations
iv) what challenges they encounter when applying the life cycle perspective
v) how they address the limited expertise in the life cycle perspective
vi) how the demand for the life cycle perspective in their organization evolved over the past 5 years
vii) what specific competencies related to the life cycle perspective the organizations anticipate needing in the next 5 years, and
viii) what competencies and skills they believe are most in demand to meet upcoming legal requirements and standards and/or to maintain a leading position in sustainability

The project is carried out within the framework of the Swedish Life Cycle Center, a national competence center for applied life cycle research at Chalmers University of Technology.

3.03.P - Qualitative Life Cycle Studies Exploring the Practical Meaning of Life Cycle Studies

3.03.P-Tu049 The Role of Value in Bridging Life Cycle Assessment and the Circular Economy Concept

Kobe Vulsteke, Ghent University; Sophie Huysveld, Ghent University; Gwenny Thomassen, Ghent University; Antoine Beylot, BRGM; Helmut Rechberger, Vienna University of Technology; Jo Dewulf, Ghent University.

Background and purpose: The circular economy concept is more and more regarded as a promising approach to achieve sustainable development goals. However, to fully harness the potential of circular economy and sustainable development approaches, it is important to understand the relationship between both. Therefore, there is a need for a comprehensive framework that not only conceptually allows one to understand their relationship, but can also serve as a basis for quantification.

Methods: In this study, through a literature review anchored in circular economy definitions, the relationship between the circular economy concept and sustainable development was examined. Based on the findings, it was apparent that the word "value" plays a pivotal role to connect both. Therefore, a framework was developed by defining different types of value, linked to the circular economy and sustainable development. Next, to improve the understanding of the framework, a demonstrative case study was used, where multiple end-of-life strategies (landfill, closed loop recycle, remanufacture, reuse) and their effects on the defined value types was assessed.

Results: Central in the developed framework is the distinction between two types of value: functional value and created value. Functional value is inherent in resources, materials, components and products, and should be preserved for as long as possible in a circular economy. Created value, on the other hand, is the net sum of handprints and footprints generated throughout the life cycle of a product, and is linked to the broader effects that different circular economy strategies have on the economy, environment, and society, and can be assessed through the life cycle sustainability assessment methodology. With the case study, mechanisms between the circular economy and sustainable development can be explained.

Conclusion: By distinguishing between two value types, this study establishes a clearer idea of the synergies and trade-offs between the circular economy and sustainable development concepts. In addition, the way is paved towards the further development of quantitative methodologies to assess both circularity and sustainability.

3.03.P-Tu051 Investigating Disparities in Environmental Impact Reporting of Battery Energy Storage Systems: A Qualitative Analysis of Industry and Regulatory Perspectives in the EU
Luka Smajila, KTH - Royal Institute of Technology; Matthew Herr, ENSTA Paris; Farzin Golzar, KTH Royal Institute of Technology.

The environmental footprint of Battery Energy Storage Systems (BESS) is increasingly under scrutiny, with concerns raised about resource depletion, emissions during production, and impacts during use-phase and end-of-life (EoL). There is a issue of incoherent approaches to assessment of BESS in stationary applications, often due to complex boundary conditions and multiple stakeholder involvement.

Moreover, inconsistencies in reported impact values across the BESS value chain, coupled with discrepancies between industry practices and evolving regulatory environments, indicate a lack of coherent understanding and shared goals among stakeholders.

This study aims to bridge this gap through a qualitative analysis of the BESS landscape in the EU. The research investigates the reported impact values from different industry actors. A comparison is made with the context of current and upcoming EU regulations, and aims to produce a framework for assessing the perspectives of various stakeholders across the value chain.

Through in-depth document analysis, the study will explore the underlying reasons for disparities in environmental impact reporting, examining the methodologies, assumptions, and motivations of different actors. It will also analyze the alignment of industry practices with the EU's regulatory framework, including the Battery Directive, the proposed Ecodesign for Sustainable Products Regulation (ESPR) and the Environmental Footprint Category Rules (EFCR) in the context of stationary BESS.

The findings of this qualitative study contribute to a deeper understanding of the challenges and opportunities in achieving a sustainable and transparent BESS industry. The proposed assessment framework can serve as a valuable tool for policy-makers, industry leaders, and researchers to identify areas for improvement, foster collaboration, and drive the development of more environmentally responsible BESS technologies and practices.

3.04 - Circular Economy and Life Cycle Assessment: Towards Sustainable Decisions

3.04.A.T-01 Could Business Model LCA be Considered a Way Towards Decoupling?
Ana Carolina Bertassini, Chalmers University of Technology; Henrikke Baumann, Chalmers University of Technology; Thomas Zobel, Chalmers University of Technology.

It is clear from the numerous environmental risks reports (World Economic Forum, Circularity Gap) that current patterns of production and consumption needs to change, otherwise, people will face increasingly severe environmental impacts while not having their basic human needs met. Following the circular economy principles, we need to change our way to consume resources in order to avoid severe environmental impacts and improve human wellbeing for all. In this case, decoupling is essential. Sustainable business models are the most powerful instrument to operationalise decoupling, through the implementation of circular business models. For this, the business model life cycle assessment (BM-LCA) was developed aiming to analyze the environmental performance of business models combining environmental and economic dimensions in a coherent, analytical way by linking the financial flows of a business model to the physical flows of an LCA. The aim of this study is to learn about decoupling from empirical evidence of studies that applied BM-LCA. To achieve that, application of BM-LCA in a number of case studies were analysed. BM-LCA includes the finantial perspective of a business model in a very different way than the tradicional life cycle costing method, connecting the finantial flows with the materials flows through coupling equations.

The BM-LCA studies show that in the studied cases the environmental advantage of the circular business model is not always significant and certain. A good design idea is accompained with added "infraestructure" that can add environmental impacts to that business model. The knowledge acquired with BM-LCA application can be used by companies to improve their business models in a way that it becomes more sustainable and that uses the resources more efficiently enabling the achievment of relative decoupling. It also can be used as a drivers to change business strategy. The results from the BM-LCA application also shows the impact of business models in the micro and macro level, enabling the comparisons of behavior of a business model in different markets for example, enabling the achievement of absolute decoupling. With BM-LCA results it also easier to recognize the interconnections between business models, meaning that business models have several subsystems, that is part of a wider system. Moreover, it is usefull to identify causal relations becoming possibel to identify how changes in the business model affects the observed system and connected ones, recognizing interrelations between effects (e.g., potential trade-offs and unintended consequences) between different sustainability domains and system scales.

3.04.A.T-02 The Reuse of Goods: a Model to Quantify the Environmental Benefits

Giulia Cavenago, Politecnico di Milan; Mary Jo Floriana Antonia Nichilo, Politecnico di Milan; Mario Grosso, Politecnico di Milan; Lucia Rigamonti, Politecnico di Milan.

Background and Purpose
The current linear economic model relies on resource extraction and waste generation. Transitioning to a circular economy, prioritizing waste prevention and reuse, is crucial for sustainable development. This study aims to define a methodology to quantify the environmental impacts associated with the reuse of goods, by developing an ad-hoc model based on Life Cycle Assessment.

Methods The proposed model quantifies the impacts associated with a used good with a life cycle approach combining the additional impacts necessary to reuse a good (transport to the reuse centre, transport to the second user, reuse) with the benefits of having avoided the life cycle of the same new good (production, transport to the first user, use, waste collection, end-of-life). In aggregating these impacts, some parameters are introduced, i.e. substitution rate (estimated by a questionnaire), and quality and energy performance rates, to reflect the users' behaviour and the qualitative characteristics of the reused good. The model was tested to evaluate the potential environmental benefits associated with the marketing of used goods at a reuse centre in Italy. In this case one or more representative products for each product category sold at the centre were chosen and analysed using the proposed model completed with the information on the weight and number of goods sold in a timeframe. Sensitivity and breakeven analyses (which helps identify the threshold where reuse shifts from positive to negative environmental impact) are suggested.

Results
The application of the proposed model to the reuse centre has put in evidence the importance of the substitution rate. If only a fraction of consumers opted to purchase a used products actually in an alternative to purchasing a new product, as it happens in the reality, the reuse results beneficial only in a few impact categories. A 100% substitution of new with used goods would instead bring benefits across all the impact categories underlying the important role of the consumer in waste prevention activities.

Conclusions
The introduction of the substitution rate and its evident impact on the results underscores not only the importance of conscious purchases but also how its integration into life cycle assessment analyses leads to an assessment that better reflects reality. The research underlines the importance of adopting proper models to evaluate the potential environmental benefits of circular economy strategies.

3.04.A.T-03 Circularity Metrics and Life Cycle Environmental Management of Wind Turbine Blades

Joan Manuel F. Mendoza, University of Mondragon; Marta Díez Viera, University of Mondragon.

Wind turbine blade (WTB) waste generation from the decommissioning of 25+ years old wind farms is expected to account up to 570 Mt in the European Union (EU) alone by 2050, representing a challenge due to its complexity for management (e.g. large and heavy difficult to recycle composite products). Currently, research projects and businesses are analysing more circular and sustainable solutions for the WTB life cycle management (e.g. reuse, repurposing, recycling and material recovery). However, there are no studies available that have yet evaluated in an integrated way (from a qualitative and quantitative perspective) the circularity and environmental sustainability of the life cycle management of WTBs to identify opportunities for improvement in the design and end-of-life management of these products, which requires to understand the scope and interlinks between improved circularity and enhanced environmental sustainability. In this conference paper a number of circularity indicators with application to the analysis of the life cycle management of WTBs are analysed. First, the major WTB life cycle management processes are mapped and characterised from a qualitative technical, economic, social and environmental perspective to identify hotspots. Secondly, the maximum possible achievable scores for the selected circularity indicators is qualitatively determined by relying on the information available in the academic and industrial literature. Finally, the potential environmental gains and trade-offs (compared to benchmark systems) as consequence from the maximum possible achievable circularity scores are explored. As a result, guidelines for the effective use of circularity and life cycle environmental approaches and metrics in the assessment of this type of product systems are explored, which can be extrapolated to other sectors using composite products (such as aeronautics, shipping and automobile industries).

3.04.A.T-04 Model-Based LCA Decision Support for Circular Steel Production

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The "Zero-defect manufacturing for green transition in Europe" (ENGINE) project, funded by the EU, aims to optimize metal production and supply chains, focusing on the maritime engine industry. A novel model-based approach, combining Life Cycle Assessment (LCA) and System Dynamics (SD), enhances sustainability assessments. Furthermore, reliability aspects of engine parts are explored, including operational condition simulation and material testing. By integrating simulation and testing technologies, material quality can be detected early, promoting circularity.
The methodology involves executing a full LCA alongside developing an SD model of the system, allowing for dynamic simulations. The study focuses on a connecting rod used in maritime engines by Wärtsilä, tracing its supply chain from steel production to assembly. The LCA, conducted using openLCA software, assesses environmental impacts and circularity of the product system. An SD model aids decision-making, comparing environmental impacts of using versus scrapping/recycling the rod.
The LCA findings highlight significant disparities in Global Warming Potential (GWP) across various processes. Closed die forging stands out with the highest impact at 29.5%, followed by raw material production (22.9%) and EAF scrap melting (13.4%). Manufacturing decisions directly affect GWP and Material Circularity Index (MCI). Doubling rod production leads to a 100% GWP increase, while MCI and CI remain constant. Recycling options outperform no-recycling scenarios, with post-steel-making recycling showing the least GWP increase. However, while recycling improves circularity indicators, this study found no direct correlation between saved CO_2 equivalents and material loop length or energy consumption.
The study concludes by highlighting the methodology's effectiveness in early material quality assessment and improving environmental impacts. It emphasizes scalability across industries but suggests further research to better reflect sustainability through circularity indicators.
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3.04.A.T-05 Product Lifetime in Life Cycle Assessment of Circular Strategies

Adeline Jerome, Chalmers University of Technology; Maria Ljunggren, Chalmers University of Technology.

Lifetime extension through, e.g., repair or reuse, is one of the key strategies of circular economy and is expected to reduce society's environmental impacts by delaying product replacement. Environmental benefits and limitations of lifetime extension have been commonly assessed with life cycle assessment (LCA) showing that product lifetime significantly influences LCA results. However, no guidance is provided to LCA practitioners on how to model product lifetime. Thus, this study provides an overview of available modelling approaches through a literature review of LCAs of lifetime extension and compares the advantages and limitations of the identified approaches on the case of remanufactured mattresses.

The review focused on LCA studies having a specific interest in product lifetime and identified three modelling steps: definition, modelling, and sensitivity analysis. The most common approach defines the product lifetime as a service lifetime (i.e., ending with the end of use not necessarily corresponding to the product's breakage) expressed in years with partitioning (i.e., distinction between initial and additional lifetime with the extension strategy), and model it as a single value with testing different values for sensitivity analysis. Two other modelling approaches were identified: using no fixed value (i.e., a parameter) or using a distribution over a population sample.

LCA results with these modelling approaches provide different insights. Modelling with a single value allows a clear analysis of life cycle stage contributions while modelling with no fixed value emphasises the evolution of the environmental impacts as a function of lifetime and the threshold for remanufacturing to be beneficial. Modelling with a distribution provides information on the average and spread of environmental impacts, allowing the identification of user groups for which lifetime extension is environmentally arguable or not.

This study thus shows that product lifetime modelling in LCA is complex and adapting lifetime modelling to the goal of the LCA is essential for meaningful assessments of lifetime extension. The findings guide LCA practitioners in making informed methodological choices for meaningful and robust assessments of the environmental performance of lifetime extension.

3.04.B.T-06 LCA Analysis of Circular Economy Business Models: A Case Study on Heat Pumps Materials Recycling and Reuse

Pietro Bartocci, RISE Research Institute of Sweden; Sachin Nande, Rayal Philips.

Background and Purpose: On the contrary of what has been done with batteries and solar panels, the debate over resource efficiency in the heat pumps industry is quite new, and few studies have discussed this topic. To analyze the circularity of heat pumps a key aspect is the business model (see for example PSS alternatives).

Methods: Two scenarios of introducing circularity in the heat pump sector are analyzed:

1. Introducing circular design practices in the design of domestic heat pumps;
2. Introducing service based business models or PSS (Product Service System) to increase the circularity of heat pumps

The two scenarios are analyzed by means of life cycle assessment (LCA). Different refrigerants and components will be taken into consideration and indexed on their circularity with three approaches:
- Material Circularity Indicator (MCI) by the Ellen MacArthur Foundation [1];
- The Circularity Index (CI) developed by Cullen (2017) [2];
- The Product environmental Footprint (PEF) formula for circularity [3].

Results: The results will be calibrated against the report "A consumer and supply chain analysis on the circularity of heat pumps : investigating the potential implementation of a circular business model" realized by the university of Utrecht in collaboration with Eneco [4].

Conclusions: The paper will brake down the domestic heat pump plant and answers the following questions: which criteria and materials have to be selected in the design phase to reduce HP impact, specifically in the end of life phase, and increase their circularity? which components can be recycled at a reasonable cost and in an economic efficient way? What is the more convenient business mode by the point of view of environmental impact and economic performance for heat pumps?

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3.04.B.T-07 Improving Circularity Assessment in Bio-Based Systems at the Product Level: A Review of Circular Economy Indicators

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Background and Purpose: The growing interest in Circular Economy (CE) practices motivates the development of simple yet reliable assessment metrics for measuring circularity in industrial systems. However, at the bio-based product level, the absence of a commonly agreed structure for assessing aspects such as biogenic carbon, carbon biological cycles, biodegradation routes, and cascading principles for bio-based products limits the use of these metrics. This study aims to analyze how CE indicators are employed in bio-based systems and offer insights into tailoring indicators to fit the characteristics of biological cycles in these industries.

Methods: A comprehensive literature review of CE indicators applied or applicable to bio-based systems is conducted. This review includes assessing their coverage of biogenic carbon, the time dimension, their link to sustainability dimensions, and applicability across various bio-based systems.

Results: The review showcases the existence of a large number of indicators already in literature to assess circularity and applicable to bio-based systems. Nevertheless, most indicators focus on general material flows, neglecting specific recycling strategies and energy needs. The time dimension is rarely addressed, and multiple approaches exist for measuring biogenic carbon. Many indicators, while not exclusively designed for bio-based systems, could be directly applied or slightly modified with a commonly agreed-upon method for accounting biogenic carbon and nutrient recovery linked to biological cycles. The review also highlights the need for a large set of separate of simple indicators to reliably assess circularity in bio-based systems rather than relying on a single indicator.

Conclusions: This study underscores the critical need for tailored indicators to effectively assess circularity in bio-based systems. The findings emphasize the importance of further research in developing such indicators and establishing consensus on evaluating biogenic carbon and nutrient recovery. These insights advance the understanding and application of CE principles in bio-based systems, facilitating the transition towards more circular industrial practices.

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3.04.B.T-08 Modelling of Upcyling According to ISO14040-44, PEF Method, and GHG Protocol

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Circular use of materials via reuse, recycling, and upcycling between companies can be considered a simple case of industrial symbiosis. A problem is when different companies desire to claim for themselves the benefits of such symbiosis. In LCA context the problem translates into a matter of how the modelling of end of life, multi-functionality, and co-production should be done, notoriously a spinous issue that is often pragmatically solved by adhering to a specific guideline – but many guidelines exist today providing contrasting guidance. This study compares the modelling of upcyling according to the ISO standards (14040-44 series), the Product Environmental Footprint (PEF), and the Greenhouse Gas protocol (scope 3 guideline and product lifecycle guideline). A qualitative assessment of scientific soundness and a quantitative comparative modelling were performed on real-world cases. Results show that radical differences exist between guidelines. ISO is less prescriptive and normative than PEF and GHG protocol, allows for using the substitution method which is arguably a better approach to model real-world causality in LCA. A common challenge is defining whether the material is a recyclable output or a co-product, and the difference between recycling and using a material in another product's life cycle. Definitions used especially in PEF and GHG protocol are inconsistent with the definitions of waste in the Waste Framework Directive (2008/98/EC). Overall, result suggest confuting the idea of environmental savings as "dividends" to be shared across entities in a network. Such benefit is only achievable via the simultaneous cooperation of both entities and allocating, dividing, sharing, assigning the whole or part of it to one of them is not a meaningful exercise. Better is to claim the benefit together and compare this to the situation without the network, as this will lead companies towards positive system change.

3.04.B.T-09 Approaching Circularity In Power Electronics

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Nowadays, power electronics can be found in a variety of applications, for example in vehicles, the energy grid or consumer electronics. In the field of consumer electronics, the end of life and recycling is regulated by law. However, this raises the questions: what happens to the power electronic components that are not covered by these regulations and which raw materials can potentially be recovered? In order to close this research gap this work maps the first steps for the modelling circularity of power electronics by carrying out material analyses and elaborating initial recycling paths.

In order to determine typical material compositions of power electronics, components from various power levels are disassembled and the components are categorized according to their materials. Furthermore, existing scientific findings in the field of waste electrical and electronic equipment (WEEE) recycling are used to investigate which recycling methods are applicable for the broad spectrum of power electronics.

Applying this reconstruction approach more than 50 different materials like metals and alloys as well various plastics were identified. An analysis of recycling strategies in the field of WEEE results in a large number of recycling routes due to the diversity of shredding processes and direct as well as sensor-based sorting methods. The process routes derived from the recycling of consumer electronics are categorised and their advantages and disadvantages are then highlighted.

This approach shows the potential offered by the transfer of circular economy aspects to power electronics in general. Furthermore, this analysis serves as a basis for closing the knowledge gap in the raw material balance in the life cycle assessment (LCA) for power electronics. Through the knowledge of the technologies already available for the recycling of consumer electronics, this work also creates a basis for the end-of-life consideration in LCA of power electronics.

3.04.B.T-10 CCU Fuels – How Circular Thinking and Climate Reductions Collide

Ingunn Saur Modahl, NORSUS - Norwegian Institute for Sustainability Research; Hanne Lerche Raadal, NORSUS - Norwegian Institute for Sustainability Research.

Circularity is a means for achieving a more sustainable society. Circularity is, however, not a goal in itself. When using circularity indicators, it is important to distinguish between indicators measuring the degree and the effect of circularity, respectively, of which LCA is a tool for the latter. When discussing CCU fuels, this is often forgotten. One argues that recycling the carbon in CO2 into fuels is part of a circular economy, implying that this is the wise thing to do.
In this presentation the authors will show how this simplification masks the fact that transforming CO2 into fuels are highly energy intensive processes, and that this energy sjould instead be used for other purposes. To show the effect of recycling carbon this way, the indicators climate change and use of primary energy resources have been used in an LCA study.
The recommended methodology for LCA of CCS and CCU systems have been used; this being connected to system boundaries, the use of system expansion to solve multifunctionality, and the inclusion of reference systems. Detailed LCA results will be shown for methanol produced from CO2 compared with methanol produced the conventional way. Three systems will be compared: a CCU system, a CCS system, and a system without capture of CO2. All systems deliver the same function to society (methanol) and are provided with the same amount of renewable electricity.
The Gibbs free energy will be used to explain fundamental thermodynamical principles, and scenarios will be used to see under which circumstances CCU fuels still can be beneficial with regard to climate effects. Results from a recent literature study on CCU will be shown to support the LCA results. The literature study concludes that production of CCU fuels/chemicals is a good way of transforming electricity, given that there is a surplus of renewable electricity, and if substituting fossil electricity generation is not possible. In all other cases, it is more climate friendly to store the CO2, and to substitute fossil electricity sources instead of using electricity to transform CO2 into a fuel. Other CCU routes were also investigated: direct utilization of CO2 seems to be beneficial and mineralisation of CO2 to replace cement can give large climate benefits. Hence, production of CCU fuels stands out as a suboptimal ‘recycling’ option.

3.04.C.T-11 Integrating the LCA Method and Circular Approaches by Using a Whole Life Carbon Assessment for Buildings

Bojana Petrovic, NORSUS - Norwegian Institute for Sustainability Research.

The Nordic EU countries are recognized as leaders in sustainability and circular economy practices within the building sector. They have implemented mandatory regulations and have introduced LCA as a standard method for calculating GHG emissions for new buildings. However, national legislations for whole life carbon assessments are not yet established. Further, there is a necessity for the inclusion of GHG emissions that go beyond the LCA system boundary. Therefore, the benefits related to reused/recycled materials presented in the D module should be taken into account. The aim of this abstract is to introduce a whole life carbon assessment using the LCA method for circular approaches.

Life cycle assessment (LCA) as a method to evaluate the environmental impact of building materials production phase, the construction phase, the use phase, the end-of-life phase and the benefits of circular approaches is used. The term “whole life carbon assessment” was used to incorporate both, positive and negative GHG emissions including the A1-D module and following cradle to cradle approach. This approach provides a comprehensive evaluation of the building’s life cycle carbon flows.

The findings highlight the necessity of implementing whole life carbon assessments for new and renovated buildings in the future. The LCA method can be used for the calculation of both positive and negative GHG emissions including the A1-D module. Considering waste processes in the C3 module, the positive (released) GHG emissions are reported for product 1, while in the D module, the benefits are expressed in negative GHG emissions. The product 1 that has a prolonged service life from the first life cycle presents zero emissions during its production phase reported for product 2 in the A1-A3 phase. To effectively track carbon flows, countries are encouraged to introduce whole life carbon assessments for new/renovated buildings.

Integrating the LCA method and circular solutions following cradle-to-cradle approach leads to sustainable utilization of new resources. Whole life carbon assessments for buildings including circular scenarios using the LCA method can significantly influence actors in the building sector to reduce the GHG impacts.

3.04.C.T-12 Trade-Offs between Technical Parameters, Environmental Impacts and Circular Economy: A Case Study on Using Recycled Fiber-Reinforced Polymer Blends

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Background and Purpose: Recycling promoted by the Circular Economy (CE) is no end in itself. Challenges of using recyclates need to be addressed to exploit their resource and environmental potential. This requires the consideration of the reciprocal relationship among technical parameters, and their implications on methodological choices in Life Cycle Assessment (LCA). Using the case of compounding different amounts of virgin and mechanically recycled polypropylene with additives and recycled glass fibers, this study aims to i) determine the role of blends as pareto-optimal ecological solutions to encounter trade-offs between material composition, processing and component properties, ii) analyse processing in detail discussing options to quantify energy consumption from laboratory trials and their industrial representativeness, and iii) reflect on potential synergies and trade-offs between environmental impacts and the CE.

Methods: To test a variety of blends and processing parameters, 32 compounding trials are performed using a twin-screw compounder (Leistritz Extrusionstechnik GmbH) with varying rotational speed and throughput rate (6-7.5 kg/h). For the simulated upscaling, the latter is increased up to 60 kg/h. Environmental impacts are calculated per component, and per equivalent tensile strength and modulus. A simple cut-off approach is chosen to model the recycled materials. The substitution potential will be discussed as implication on the effectiveness of the CE. Inventory data are collected from laboratory experiments complemented by ecoinvent 3.9.1 cut-off and literature. EF3.1 is chosen as impact assessment method using OpenLCA.

Results: Following hypotheses will be verified: i) Blend composition and processing parameters have a significant influence on energy demand of the compounding process and environmental impacts, which will also vary significantly in regards to the three functional units. ii) When upscaling, there will be a shift in required energy type and amount, leading to a reduction in environmental impacts at higher throughput rate. iii) The waste potential will be compared to the demand of potential industrial users regarding their volume and material requirements.

Conclusions: The discussion on the interplay of technical and methodological parameters of modelling recycling in LCA (including the role of blends), the inference on the CE, and the quantification of upscaling effects can also be relevant to other materials and processes.

3.04.C.T-13 Circularity Measurement and Assessment: Applicability of ISO/FDIS Standard 59020 and Life Cycle Assessment to Electric Vehicle Batteries

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Circular Economy is a core aspect of multiple private and public efforts for achieving sustainability of products, organizations and at regional level, specially aiming to reduce the use of resources, waste generation and therefore environmental impacts. In particular, electric vehicles (EVs) are identified as one of the key sectors of interest for circular economy implementation due to their increased growing demand, resultant from the current measures for decarbonizing transportation. Although EVs constitute a less impactful alternative to combustion engine vehicles, there are still multiple challenges mainly related to their battery. Supply risks of critical and strategic raw materials, together with the high environmental impacts during battery production and low recovery rates of materials at the end of life, are some of the key issues of the sector. Moreover, there is a lack of appropriate tools evaluating the impact of circular strategies in a standardised and accessible way for this product category. In the frame of the European Project "Innovative and sustainable high voltage Li -ion cells for next generation (EV) batteries – IntelLiGent", this work aims to analyse the applicability of the indicators proposed by the ISO/FDIS standard 59020 for measuring and assessing circularity, specifically in Lithium-ion batteries for EVs, and to identify how Life Cycle Assessment (LCA) can support this evaluation. Furthermore, this study discusses the challenges and opportunities in the use and calculation of these indicators in terms of accessibility to data and representativeness of the indicators. Requirements for the calculation of the carbon footprint of EV batteries and recycled content targets from the new EU Batteries Regulation 2023/1542 are considered. Resource inflows and outflows are identified as the key indicators for EV batteries but presenting issues in terms of conceptualisation of circular resources, where criticality and impact factor of battery materials are not considered in the calculations. The Life Cycle Inventory from the LCA study provides around 65% percent of the required data for the application of circularity indicators, while LCA results are used as complementary information for a more comprehensive understanding of the impact of the product and for decision making.

3.04.C.T-14 Is the Current LCA Practice Really Measuring the Environmental Consequences of Material Circularity?

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Industry is nowadays under pressure to fulfill and align with many environmental policy-related requirements, at different scale (product, process, plant) and that in many cases requires the application of methodologies that are not coherent each other. Companies are asked to report on circularity and on other environmental aspects (e.g. Climate change), and LCA is mentioned (or prescribed) as the methodology to quantify results and track progresses.

A key point of discussion in the scientific community is the waste and scrap modeling. In the current LCA practice, a scrap from a previous and different product system is basically marked as recycled material, then it is considered to substitute (partially or totally) virgin materials. While such consideration seems to be aligned with the circular economy concept to feed used materials back into the product system (among others), it does not necessary capture properly the environmental footprint of a product using that scrap as input. Indeed, there is not consideration about the scrap source (pre or post-consumer) and, in the case of pre-consumer scrap, about the origin of material from which the scrap originates (primary or post-consumer).

While existing LCA standards do not specify modeling requirements connected to scrap source, few guidelines and/or product category rules require to consider the pre-consumer scrap as a co-product. This affects the footprint of products using pre-consumer scrap, which can be higher or lower, depending on the material and/or the specific step of the value chain.

The article presents two simplified case studies on metal and plastic products where scrap is used as input, as basis for arguing about the implication in the environmental footprint assessment and on consideration about product's circularity. Results shows that when the pre-consumer scrap is considered material burden-free, the impact of the product can be even 80% lower (in Climate Change) compared to when it is assigned with a material burden. In addition, in this second case, the material becomes the first contributor to the product impact.

The study raises the point of what each value chain actor has and can to communicate to avoid bias. The LCA is powerful tool to allow a conscious selection of products by consumers. However, when used to also support the environmental improvement of the businesses and sectors, further considerations should be done on the way in which the circularity benefit is quantified.

3.04.P - Circular Economy and Life Cycle Assessment: Towards Sustainable Decisions

3.04.P-We020 Circular Economy Implementations in Industry – Towards a Broader Use of Sustainability Approach

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Circular economy is expected to transform the way we produced, use and operate, and provide recycle services. Circular economy encapsulates a wide range of services including repair service and collection services and recycling services. While the industry is developing better ways of saving energy and material, the efficient use of resources is still a challenge. How are circular economy implemented in the industry? The research projects include practical solutions and application in the automotive sector, in the plastics sector and in the building sector. The research method is based on a LCA based approach. The examples from industry show that the dominant use of impact in industry is the use of carbon footprint.

Less is known on other sustainability aspects. For example, the use of secondary materials and critical or biobased resources. For example, the direct and indirect social benefits of circular solutions. The direct effect of more workforce locally on repairing service. The indirect effect of using less resources, such as critical resources and less mining. To promote the circular economy a broader sustainability approach is needed.

3.04.P-We021 Comparative Life Cycle Assessment of Fabric from Post-industrial Polyethylene Terephthalate (PET) Waste vs Virgin PET

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Global population growth and improved living standards in recent decades have boosted textile production and consumption, making it widely recognized as one of the most polluting industries. This work has been conducted as a part of the EU Horizon project "PRecycling", which focuses on plastics recycling from and for home appliances, toys, and textiles. In the apparel industry, 97% of the feedstock comes from virgin resources, with only 1% recycled in a closed-loop and 2% sourced from other industries. Hence, this study aimed to compare the potential environmental impacts of fabric made from post-industrial PET waste, and virgin PET, respectively. The life cycle inventory data was obtained from Centexbel, a scientific and technical research centre specializing in the textile and plastics industry. Life cycle impact assessment is performed using the EF 3.1 method in SimaPro 9.5 software. The findings of this study have shown that the climate change impact of fabric made from virgin PET is three times higher than that of post-industrial PET waste. The main contributing processes and hence biggest improvement potentials for the route via PET waste were the filament extrusion process and the shredding process. The former has a significantly high electricity consumption, whereas the latter includes the enduring environmental footprint of the previous life cycle of PET waste. In the virgin PET-to-fabric route, the shredding process emerges as the predominant contributor across all impact categories as the virgin PET carries the environmental burden of its manufacturing process. Ultimately, our study emphasizes the substantial environmental benefit of fabric derived from PET waste over that produced from virgin PET, highlighting the importance of sustainable material sourcing and recycling in mitigating environmental impacts.

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3.04.P-We022 From Waste to Resource: Assessing Circular Economy Strategies for Bread Surplus

Pedro Brancoli, University of Borås.

Bread waste is a significant issue in Sweden due to the high volumes generated throughout the supply chain. At the same time, the return system established in the supply chain enables a flow of bread waste that is not contaminated with other food waste products. This creates an opportunity for alternative valorisation solutions within the framework of circular economy and beyond common municipal waste treatments.

This study uses life cycle assessment to evaluate the environmental impacts of different management options for surplus bread, including source reduction, donation, animal feed, ethanol, beer production, anaerobic digestion, and incineration. Additionally, a novel process for converting surplus bread into a high-value fungal food product via solid-state fermentation with N. intermedia was evaluated, aiming the integration of environmental considerations into the development of the technology in its early stages of development.

The results indicate trade-offs between the different impact categories analysed. Nevertheless, a hierarchy is supported where source reduction offers the highest environmental savings, followed by use as animal feed, donation, beer production, and ethanol production. Anaerobic digestion and incineration provided the lowest environmental savings, especially in a low-impact energy system. The analysis of the novel solid-state fermentation process showed that fungal biomass produced from surplus bread could serve as a substitute for traditional food products, offering a lower environmental footprint than conventional alternatives, with potential implementation in supermarkets and bakeries. The hotspot analysis results reveal that the selection of the medium for inoculum production significantly impacts both environmental and technical indicators, such as protein content and lag phase.

The current distribution system for bread in Sweden facilitates the implementation of more environmentally friendly valorisation, since two of the largest barriers for implementing these options—organisational effort and proper logistics—have already been overcome. The study also shows that the solid-state fermentation process can effectively retain bread waste in the food chain, maintaining its food function, increasing the availability of infrastructure for surplus management, and reducing its environmental impact. Furthermore, the research allowed for the identification of environmental hotspots and trade-offs that support process optimization

3.04.P-We023 The Role of Circular Economy in the Machinery Sector: A Comprehensive Analysis of Key Technologies to Reduce its Environmental Footprint and Resource Use

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The machinery sector represents not only one of the largest material stocks but also of the largest contributors of the environmental impact within the industrial sector. Circular economy (CE) has emerged as an alternative economic model to decouple the resource and environmental footprint from product service provision. However, the lack of studies assessing the interplay and impact of the CE on this heterogeneous sector hinders the understanding of its potential and implications. This work aims to: (1) identify and categorize the most representative technologies from the machinery sector, and (2) describe the current state-of-the-art research concerning the machinery sector and CE, including an assessment of ongoing technological trends in the sector and identification of research gaps related to environmental assessments of these technologies.

Through a literature review and statistical analysis, the most relevant technologies are identified based on their economic, environmental and material significance. Various perspectives are considered to better identify the technologies for which the circular economy can play a more important role, especially considering the implementation of potential "slowing", "narrowing" and "closing" the loop strategies.

Mixed outcomes are anticipated across the different categories analyzed (i.e., economic, environmental, material) for the different machinery technologies. Notably, energy consumption during the use phase is expected to be a significant parameter from an environmental perspective; since most of the studies from this sector will have energy consumption and energy efficiency as a central point of emphasis. Nevertheless, material and economic

considerations will help to better assess their relevance considering technology developments and ongoing transitions.
This comprehensive analysis contributes to identify the most significant machinery technologies in the context of circular economy, serving as an initial step towards integrating the economic and material implications of CE assessments for this sector. By establishing a clear framework for this heterogeneous sector, the analysis seeks to steer future research, particularly in environmental life cycle assessments (LCA) of these technologies, and to evaluate the CE potential for reducing its environmental footprint and resource use.

3.04.P-We024 Multifunctionality In The End Of Life Of Products: Is Circular Footprint Formula The Answer?

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End of life (EoL) of products is a typical stage where multifunctionality problems emerge in LCA studies whether due to reuse, recycling, and/or energy recovery activities. Many approaches to deal with multifunctionality in general, and EoL in particular, have been heavily discussed in literature. One of these approaches is the Circular Footprint Formula (CFF), introduced in the 2017 version of the Product Environmental Footprint (PEF) guidance to replace the EoL formula in the preceding 2013 PEF version. However, the PEF does not really provide sufficient information on the scientific reasoning that led to the CFF formula. Therefore, in this work, we analyze the CFF formula from conceptual and practical perspectives with the help of a simple product system example.

The analysis showed certain problematic points in application. The most prominent among these is that CFF adopts a material flow perspective, while LCA-based PEF is concerned with products and product systems. It remains unclear how products consist of various materials can be handled with the formula, which also raises the question of its applicability to complex systems such as electronics or automobiles. Another aspect of complexity is the material cascading between a long chain of different product systems. For allocation to happen correctly between these systems, a detailed knowledge of the far past and far future systems should be available, which is often impossible in the real world. Moreover, we explore where CFF positions itself between attributional and consequential modelling of LCA, concluding that it lies somewhere in between as it borrows mixed concepts of both approaches.

Zooming in, the simple example we tested showed some details that require further guidance in the application of the equation. For instance, the provided predefined values of A, B and R(s) could cause unjustified and hence unfair burden allocation between the linked systems. Another puzzling detail is that the burden of virgin material consumption is shared between the first system and all the subsequent systems, but this is not the case of disposal burden, which is allocated entirely to the last system.

In conclusion, we think further guidance and improvements are still needed for the CFF to become more accepted in LCA community, not only scientifically but also from applicability point of view. We recommend a top-down approach which commences with defining what a multifunctionality problem actually is, looking into possible solutions and the consequences of these solutions, then translating this via scientifically sound routes into better methods and formulas, instead of starting from the formulas and methods themselves

3.04.P-We025 Towards Sustainable Synthesis: Exploring Egg White as a Possible Gelation Agent for Eco-Friendly Activator Materials in the Realm of Plastic Pyrolysis

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Nowadays, the pyrolysis of plastic waste, often combined with the use of activators to improve the efficiency of hydrocarbon splitting, is seen as a replacement for waste incineration due to its reduction of direct CO_2 emissions. When seeking viable and sustainable synthesis routes for activator materials like $FeMn_2O_4$ (FMO) wet chemical methods emerge as promising candidates. Here, egg white steps into the spotlight as a well-known and often proclaimed eco-friendly gelation agent, renowned for its commendable foaming, gelling, and emulsifying properties, facilitating nanoparticle formation. However, our investigation revealed challenges in obtaining phase-pure material despite engineering various synthesis parameters (namely egg white content, precursor concentration, calcination time, and temperature). X-ray diffraction for crystal structure analysis, scanning electron microscopy for particle morphology, and energy-dispersive X-ray spectroscopy for elemental composition analysis were conducted on the produced samples. It was hypothesized that the strong binding affinity of ovotransferrin, a protein in egg white, to iron and manganese may affect the formation of phase-pure spinels. Additional testing beyond the aforementioned methods is still required to validate the hypothesis. Simultaneously, our aim extends beyond mere synthesis and ensued functionality; sustainability should already be addressed during the early stage of materials development. Merely labeling a product as “eco-friendly” due to its natural origin is inappropriate; such claims must be substantiated by data. Therefore, the search for proper synthesis conditions is accompanied by an attributional cradle-to-gate Life Cycle Assessment (LCA) study. The declared unit is the production of 1 g of FMO powder on the lab scale. Electricity emerges as a primary contributor to environmental impacts, alongside the significant footprint of egg production. Thus, for the studied synthesis route, using minimal egg white in the synthesis is advisable, and it cannot be considered “eco-friendly”. Subsequently, synthesis routes without egg white as a gelation agent but otherwise the same chemical precursors were tested and assessed via LCA. In conclusion, our approach underscores the indispensable fusion of LCA methodology with materials development especially at an early stage. By relying on clear evidence rather than assumptions, we aim for truly sustainable development.

3.04.P-We026 Optimizing Performance of Global Mobility and Relocation Using Life Cycle Assessment (LCA)

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Global mobility and relocation services, including the movement of people, offices, and household goods, are essential to international business operations. However, these activities often have significant environmental impacts, particularly in terms of greenhouse gas emissions and resource consumption. These impacts arise from the packaging materials used and the emissions from transport. Around 78% of the total increase in greenhouse gas emissions between 1970 and 2010 came from CO_2 emissions from the combustion of fossil fuels and industrial processes. This emphasizes how important it is to have all-encompassing strategies that address the wide range of environmental impacts to truly achieve sustainability.

Packaging has been the subject of many LCA studies, and the traditional method of packing for relocation involves shrink wrap, bubble wrap, poly chips, and cardboard boxes many of which have only one use. To increase sustainability, companies are looking for opportunities to reduce their impact and one option suggested has been the use of more reusable systems.

This study uses LCA and systems thinking to identify where the most significant impacts lie. This will enable us to address the high-impact environmental aspects of these services, with an emphasis on the balance of environmental sustainability, customer acceptance, and operational costs.

The research initiates with a comprehensive assessment of our industrial partner's current operations. This has led to the development of a series of scenarios for relocations. Using these, we can show the impacts of potential changes in operations on costs and environmental outcomes, including greenhouse gas emissions. This will be developed to determine environmental footprints of several scenarios, including novel packaging materials and transportation options.

Initial results of the scenario modeling show where the impacts lie across traditional systems and identify areas for improvement and innovation. Complex trade-offs between reusable and disposable materials exist, and this work highlights the short- and long-term opportunities for change.

The study emphasizes the role of LCA and systems thinking in improving the sustainability of global mobility operations. The findings help to inform strategic decisions that promote environmental responsibility while also ensuring economic viability and customer satisfaction. This approach establishes a standard for sustainable practices in the global mobility industry.

3.04.P-We027 Sustainable Pathways: Empowering Decision Making Through Environmental Analysis in the Plastics Industry

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In early project stages, comprehensive decision analyses often neglect environmental impacts, despite the potential of methodologies like Life Cycle Assessment (LCA) to foster sustainable decision-making. This sustainable pathway must be employed in the plastics industry, which had a turnover in Europe of 405 billion euros in 2021 and is now being applied to the Portuguese plastics industry, in the INOV.AM Project. The present work aims to analyse the environmental impacts of a specific polymer component for a water heater for the first design simulations. This study followed the LCA methodology according to ISO 14040-44 standards, and the goal was to assess the environmental impacts of producing a high-performance polymeric part for a condensation unit. The baseline product, with 0.358 kg, is made of polyphenylene sulphide (PPS) with 40% glass fibre. Two design options were analysed: Design1, produced with PPS and a mass of 0.268 kg, and Design2, made of polyoxymethylene (POM) with 25% glass fibre and 0.268 kg. The declared unit is the production of a polymeric part, in a cradle-to-gate approach, including the mould production and the injection process. The inventory was led using primary data from a mould production company, and secondary data from the Ecoinvent database and Industry Data2. The ReCiPe Midpoint (H) assessment method was employed. Comparing the injection process of the baseline product with Designs1 and 2, a reduction of impacts is evident. Design1 achieves a 25% reduction, while Design2 achieves an impressive 91% reduction in environmental impacts. The results obtained for the baseline product indicated that the injection process significantly contributes to the environmental impacts, accounting for 99.6% of the total impacts, while mould production contributes only 0.4%. This study employs an integrated decision-making process to evaluate and validate the sustainability of two design alternatives alongside a baseline product. Different materials and masses were compared, showing that the switch in materials yielded larger environmental impact reductions than mass decreases. The integration of eco-design with structural and environmental simulation methodologies has significantly enhanced the analysis and assessment of innovative solutions for high-performance polymeric products and also provided crucial insights for decision-making in the initial phases of product development, with a strong emphasis on minimizing environmental impacts.

3.04.P-We028 Environmental and Economic Performance of Municipal Wastewater Treatment Plant: A Case Study - Søndre Follo Renseanlegg, Norway.

Alifiya Ikhsani, University of Agder; Dinindu S. Ratnaweera, DOSCON AS.

Background:
Søndre Follo Renseanlegg (SFR) is a municipal wastewater treatment plant (WWTP) in Vestby, Norway. The plant has a capacity of 25,000 p.e. It uses mechanical-chemical treatment processes as well as sludge treatment with energy recovery. SFR met the requirement set by the Norwegian Pollution Control Authority. Nevertheless, the laws become more stringent, requiring the facility in Norway to follow the revised Urban Wastewater Directive (UWWTD). Member states are obligated to satisfy nitrogen removal and report energy audits to reduce energy consumption and increase the use of renewable energy. Therefore, SFR is currently investigating different potential operations. A pilot test for one alternative solution will begin in June 2024.

Purpose:
Life cycle assessment (LCA) helps identify environmental performance when upgrading WWTP. Decision-makers should understand and weigh the trade-offs between environmental benefits such as improved water quality and environmental impacts like higher energy consumption and carbon footprint. The WWTP system's complexity makes integration of LCA and life cycle cost analysis (LCCA) using site-specific data in SFR important. The goal of this study is to assess the environmental and economic performance of current and alternative operations.

Methods:
This study integrated ISO 14044/46:2006 LCA, LCCA, and net present value. Environmental and economic performance of SFR will be quantified. One m3 of treated wastewater is used. The system boundaries include piped wastewater entering the plant, energy and mass input and output flows from WWTP operation to byproduct transport (gate-to-gate). The LCA study used SimaPro v9.5.0.1 and Ecoinvent v3 with 80% on-site data considered. Environmental impact assessment calculated using CML IA Baseline v3.05, while Environmental Prices v.100 was used for monetary valuation.

Findings and value-added:
This study's preliminary findings indicate that the alternative operation with MABR system, new biogas reactor, and reduction of

incoming sludge from other facilities is the most environmentally and financially viable treatment option. After comparing the alternatives, the contribution of each unit process to the environmental impact categories will be investigated further. Finally, analysis will be conducted to examine the differences in costs of construction and operation phases of different alternatives, with the aim of identifying best viable alternative operations.

3.04.P-We029 Challenges and Opportunities in Carbon Fiber-Reinforced Polymer Composites Circularity: A Prospective LCA Case Study

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Carbon fiber-reinforced polymer composites (CFRP) are pivotal for the advancement in modern engineering and manufacturing due to their exceptional properties, which enable their use in a wide range of applications, including aerospace, automotive, and energy sectors. The market demand for such materials is increasing while their high embodied energy and reliance on non-renewable resources, primarily due to carbon fiber precursor polyacrylonitrile (PAN), have drawn attention to the need for better end-of-life management. In response to heightened sustainability awareness, circular economy (CE) is exemplified by measures such as recycling in the sector. Innovative recycling technologies, e.g. pyrolysis and solvolysis, have demonstrated the potential to retain certain properties of the reclaimed fiber, making recycled carbon fibers appealing for various middle to lower-tier markets and applications.

Albeit advances in recycling technologies promote carbon fiber circularity, a holistic and comprehensive assessment is required to evaluate the environmental performance and trade-offs of such activities. Life cycle assessment (LCA), a multi-criteria methodology, serves as an ideal tool to measure CE progress.

Hence, our proposed research focuses on a prospective LCA examining carbon fiber recycling scenarios, aiming to explore the following research questions: 1) What are the environmental impacts associated with each CE practice and their temporal feasibility of implementation (2030 and 2050)? 2) What are the overall environmental impacts when recycled carbon fiber is remanufactured to meet product quality requirements in practical application? 3) How effectively could LCA be implemented to measure the CE practices? In total, two promising recycling technologies, four geographical distinctions (leading CFRP producer countries worldwide) are assessed using two functional units and corresponding system boundaries.

The insights gained from this study can contribute to the broader discourse on the practical implementation of circular economy strategies. Prospective LCA allows for identification of break-even points and support informed decision-making when prioritizing certain practices. Additionally, this research underscores the importance of understanding different LCA modeling settings to provide different incentives.

3.04.P-We030 Data Center It Hardware Refresh Driven by Life Cycle Assessment for a Circular Economy

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In a data center, the old IT hardware is replaced with latest version to achieve better performance, and this process is called as a hardware refresh. Typically, hardware refresh is performed every three to five years for attaining improved performance and energy efficiency. Currently, the typical server lifecycle is very linear. Hence, most servers are discarded as electronic waste after a refresh. Existing research focusses on the impact of hardware refresh on energy efficiency, performance and lifecycle costs which has further led to increased importance of these factors in refresh decisions. However, it is imperative to factor in the environmental impact along with other factors to drive hardware refresh decisions and incorporate a second life possibility. To do the same, the scope of this work covers second life possibilities for servers after a refresh by defining use cases within recycle, reduce, reuse, refurbish, reliable and repair categories, based on a comparative cradle-to-grave life cycle assessment (LCA). Firstly, a life cycle assessment is undertaken to determine the impacts of performing the routinely hardware refresh for ‘x’ number of servers used to meet an IT load where the ‘grave’ part is modelled as discarding the servers to a landfill. For the second part of the LCA the various second life use cases applicable for the servers are modelled and the results of the same are compared and analysed along with the landfill scenario. Furthermore, a third scenario will analyse the varying impacts of prolonging the server hardware refresh and then apply the second life scenarios. The results of that comparative LCA is expected to provide insights of the environmental impacts to drive hardware refresh decisions and to encourage second life scenarios which will be one step forward in the direction of circular economy in data center environment.

3.04.P-We031 Combining Material Flow Analysis and Life Cycle Assessment to Define Regional Reuse Strategies for the Steel Industry

Chloe Ruda, Viry - Fayat Group; Nalan Gulpinar, Durham University; Fang Liu, Durham University; Elizabeth Gibson, Newcastle University; Linsey Fuller, Procter and Gamble.

With circular economy gaining interest in the construction industry, the number of initiatives aiming at reusing structural steel is growing. If well-protected from corrosion, steel is indeed one of the most durable construction materials. In countries with a long industrial history, old steel buildings such as warehouses can be seen as urban mines that provide structural elements for new construction projects, thus preventing negative impacts from new production. Quantifying and characterizing the available steel resources is a key issue for establishing both the economic model of reuse and realistic, comprehensive reuse scenarios to be assessed using LCA.

We propose a framework to evaluate the environmental impacts of steel structures’ reuse through a two-step approach combining Material Flow Analysis (MFA) and Life Cycle Assessment (LCA).

The MFA framework is based on an extensive building survey supported by an existing geographic-information-system (GIS) database that covers the French territory. Buildings from the database are statistically allotted into homogenous archetypes, defined by a set of parameters including construction system, period of construction, geographical area and building use. Specific features such as type of structural system, steel fabrication technology, type of anti-corrosion treatment etc. are also set to further describe each archetype. Thanks to the archetype approach, steel stocks that could potentially be recovered in the coming decades are computed and characterized. Aggregating stocks on different regional scales also makes it possible to identify high-potential areas for the reuse business.

Mapping and characterizing steel stocks then enables to spatialize scenarios. Supply distances are parametrized. In LCA background databases, processes that meet the needs of refurbishment and waste management operations are selected, provided they are available locally.

The workflow detailed above has the potential to support spatial optimization of supply distances considering the location of mines, reconditioning facilities and construction sites, thus backing up key decisions in the development of the steel reuse industry. Our approach, based on assumptions on regional deconstruction rates, could also be combined with prospective life cycle inventories to look at the benefits of reuse compared to the impact reductions achieved by future cleaner steel production technologies.

3.04.P-We032 Chemicals Production from an Alternative Carbon Source: Techno-economic and Environmental Aspects of Supply Chain Design

Ariane Silveira Sbrice Pinto, Durham University.

First generation sugar sources are widely used. The highest contributors of the carbon footprint of glucose products are related to agricultural emissions during the crop's cultivation (sugarcane, corn, e.g.), costing significant environmental impacts for subsequent products in the supply chain. Improvements in the energy efficiency of existing diesel irrigation pump systems for irrigated corn production can significantly improve the single environmental score and reduce the global warming potential (GWP100a) for corn production in the Western United States Corn Belt. Only the corn production could account 95% of United States feed grain production emissions and 28% of global corn production over the period of 2013 to 2017. In this context, the use of alternative sources to produce sugars is promising to mitigate greenhouse gases emissions by avoiding and/or mitigating the use of raw resources, cultivation, harvesting emissions, and reducing the plantation area. However, the use of alternative feedstocks to produce high-value chemicals, as glucose, might consider ex-ante analysis of techno-economic and environmental aspects due to the low technology readiness level. Food waste (FW) is a promising feedstock for recovering fermentable sugars to produce chemicals due to its rich nutrients and carbohydrate composition (30–60% starch - w:w). Opportunities and bottlenecks of recovering FWs into chemicals to mitigate the supply chain carbon footprint were investigated by analysing the manufacturing process. Techno-economic and environmental aspects were considered by life cycle assessment (LCA) and techno-economic analysis (TEA) of the large-scale process. SuperPro Design ® software was used for TEA and Brightway2 for ex-ante and prospective LCA (Ecoinvent and PREMISE databases). The benchmark factory was glucose from corn (GL). Although FW was not profitable under default operational conditions, trading carbon credits due to avoided emissions could provide enough financial support for this investment. Glycerol consumption, final productivity, and carbon offsetting due to waste's valorisation were the key contributors for the variance of the emissions under inhibitory operational conditions. Future studies might validate experimentally the impact of inhibitory effects by using sugars without further purification during chemicals production.

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3.04.P-We033 Assessing the Environmental Benefits of Refurbishment: A Case Study of Self-Contained Emergency Lighting Luminaires

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Growing production of electronic waste (e-waste) poses significant environmental and resource sustainability challenges globally. Effective e-waste management is imperative to mitigate these concerns. The Circular Economy model, which seeks to decouple economic development from resource consumption, offers a promising pathway. One of the effective strategies deployed in this model is refurbishment that aims at prolonging product lifecycle. This study scrutinizes the environmental benefits of refurbishing a Self-Contained Emergency Lighting Luminaire (SCELL) versus replacing it with new-generation (virgin material and higher efficiency than base luminaire) counterpart.

We conducted a comprehensive Life Cycle Assessment (LCA) of SCELL in accordance with ISO 14025 using PSR-0007-ed2.1 and PCR-ed4. The study employes the EN15804 standard approach, utilizing EIME V6.2 software, focusing on EF 3.1 set of environmental indicators. We compared two scenarios over a 20-year timeframe for France as end market, considering the base luminaire (virgin material based) being already on the market and replacing it either (1) by refurbished luminaire, or (2) by new generation luminaire in the same family. Each luminaire's reference service life was set at 10 years, in line with PSR, and all the impacts were calculated relative to scenario where existing product is replaced with same base luminaire.

Our findings indicate 14.4% reduction in climate change impact from cradle-to-grave when replacing with a refurbished luminaire compared to a 13.6% reduction when upgrading to a new-generation luminaire. The refurbished luminaire however demonstrates a substantial decrease (42%) in the manufacturing phase impacts due to reusing the parts. In contrast, the new-generation luminaire shows a reduction in the use phase (22%), benefiting from improved energy efficiency and reduced power consumption.

Regarding resource use and minerals, the new-generation product exhibits an overall 44% impact reduction, outperforming the refurbished product's 6% reduction. This outcome is predominantly influenced by the battery technology; despite the refurbished luminaire reusing over 65% (w/w) material, the new-generation model's advanced battery technology, which is approximately one-third the weight, has lower replacement frequency and lesser resource use and minerals impacts.

Thus, relying solely on refurbishing process without incorporating new technology may not be the most effective approach. Hence, it's essential to incorporate latest technological developments along with refurbishment as an environmentally better alternative. This holistic approach ensures that the benefits of refurbishing are maximized while keeping up with the pace of innovation.

3.04.P-We034 LCA as Decision Support Tool for Multi-Functional Systems in a Circular Economy: the case of Anaerobic Digestion of Waste and Recycling Contaminated Soil

Hanne Lerche Raadal, NORSUS - Norwegian Institute for Sustainability Research; Kari-Anne Lyng, NORSUS - Norwegian Institute for Sustainability Research; Mehrdad Ghorbani , NORSUS - Norwegian Institute for Sustainability Research.

Background and Purpose:

When using Life Cycle Assessment (LCA) as a decision support tool in multi-functional systems, it is crucial to clearly define the specific decision the LCA aims to inform. Additionally, it is essential to identify all stakeholders and delineate their respective responsibilities within different segments of the value chain. Environmental product declarations (EPD) and different approaches for modelling recycling in LCA require standardised methods to allocate the burdens and benefits from recycling processes to avoid double counting at system level. However, recycling systems represent multifunctional systems as they connect two (or more) product systems and provide two functions: 1) treat the waste from one product/process, and 2) use of the waste resources as feedstock. Additionally, the recycling process means that an alternative waste treatment process is avoided. When using the traditional LCA footprint methods for products, such as EPDs some benefits of the multi functionality is not regarded.

Methods:

In our study we explore the implications of different functional units and system boundaries for two different multi-functional systems: anaerobic digestion of organic waste and recycling contaminated soil. Both systems can be considered as waste treatment services and producers of several recycled products and involve a range of decision makers with different perspectives. Different assumptions regarding end-of-waste status are also taken into account when defining system boundaries.

Results:

The results show that standardised product oriented LCAs, such as EPDs, might lead to undesirable decisions, as the entire benefits of multi-functionality are not included.

Conclusions

The study shows the importance of considering the entire burdens and benefits on an overall system level when analysing multifunctional systems. This implies a need to adapt the EPD system towards a more circular society where activities are connected, and the use of waste resources is rewarded.

3.04.P-We035 Bin-To-Product: Maximizing the Use of Plastic Waste as a Resource While Minimizing Environmental Impacts

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To limit the environmental impact of plastic production and pollution, governments and companies have pledged to increase recycling percentages. However, due to a lack of high-quality recycled feedstock, only 6% of plastic products were derived from recycled plastic in 2018 globally. Ineffective consumer separation behaviour and high costs for a waste sorting infrastructure hinder the processing of plastic waste streams into high-quality recycled feedstock that are fit for recycling and re-use. In this study, several plastic waste management strategies are compared to assess their effect on the quality of the plastic waste streams and resulting recycling pathways followed. Each plastic waste management strategy is defined by the waste composition, collection strategy and separation behaviour of neighbourhoods. The carbon footprint of each strategy is assessed using Life Cycle Assessment and the circularity of each scenario is quantified using a circularity index based on recycled material quality levels. Using our findings, we can identify the environmentally optimal plastic waste management strategy, i.e., largest environmental benefit and circularity indicator, for a given composition of household waste and current infrastructure and policy. Several case studies of municipalities in the Netherlands, including Amsterdam and Nijmegen, are used to demonstrate what the most environmentally friendly plastic waste treatment strategy is. Additionally, the variability in plastic waste separation among neighbourhoods is considered to evaluate whether policy targets could be reached through behavioural interventions. Ultimately, the outcome of this study provides policymakers with an overview of where interventions could take place to reduce the environmental impact of several plastic waste management strategies and how policy measures could increase recycling percentages. Additionally, insights are generated on how plastic waste management can be utilized to consider the use of plastic waste as a resource and thus improve the quality of recycled feedstock that enters the market.

3.04.P-We036 Towards Prospective Circularity Assessment of Batteries

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With the mobility transition to reach policy targets such as net-zero, the e-mobility sector and consequently the demand for batteries are growing rapidly. This leads to an increased demand for several raw materials, the sourcing of which is critical. The mobility transition is increasingly accompanied by life cycle assessment (LCA) to ensure a sustainable transport sector. For example, the EU battery regulation demands the declaration of the carbon footprint for vehicle batteries on the European market and also introduces thresholds later on. Therefore, a harmonized LCA approach is needed. The use of strategic or critical raw materials also leads to an establishment of circularity strategies in the battery sector. The implementation of these strategies is currently mostly based on the micro level with design for recycling, recycling and reuse. The evaluation of these strategies should integrate information on a mesa and macro level. To use recycled materials, qualitative, quantitative, temporal and geographical considerations on their availability are needed. To estimate the availability of recycled materials, the lifetime of batteries, collection rates as well as recycling process specifications such as recycling efficiency and recycling purity are needed. These are aspects that cannot be captured directly in an LCA. Additionally, the LCA has the focus on material inputs and outputs as well as process emissions. Material losses and a specification where these lost materials end up is often not considered. Therefore, the LCA is often based on incomplete mass balances. However, in the context of valuable raw materials, it is quite important to track their flow and to reduce losses as much as possible. These described challenges highlight that in the context of a sustainable mobility transition and increased circularity of materials, the LCA reaches its limitations. Thus, we develop a framework for the prospective circularity assessment of traction batteries. The framework suggests how to perform an MFA on different levels – the process level to quantify losses and to track their destination as well as on economy level to estimate the availability of secondary material. The results of the MFA are used to extend the LCA to support sustainable multi-dimensional decisions for the transport sector. Results from a first application of the framework will be presented as well.

3.04.P-We037 Life Cycle Assessment of a Single-Use, Battery-Powered Surgical Stapler Used in Minimally Invasive Surgery

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Background and purpose: Between 2000 to 2018, there has been a 462% increase in the use of minimally invasive surgery (MIS). Many surgeons now prefer MIS over open surgery due to its many benefits such as smaller incisions and scars, less pain on patients, less complications, and shorter hospital stays. The operating room is considered the most resource-intensive area of a hospital, and surgery is thus an important focal point to understand healthcare-related carbon footprint. The trend towards MIS involves the use of more single-use instruments such as surgical staplers, which may be liable for negative environmental impacts. Therefore, there is a need to assess the environmental impacts of such devices, identify existing hotspots throughout their life cycle stages and understand their contribution to the entire surgical value chain.

Method: In this study, we analysed the environmental impact of single use, battery-powered surgical stapler using life cycle assessment method. The entire life cycle from cradle to grave was considered in the analysis.

Results: Manufacturing of components had the highest contribution to climate change impact. Of this, the majority was attributed to the manufacturing of electronic components. The current end-of-life (EOL) strategy for the surgical stapler is incineration which account to a small contribution. Changing the EOL strategy to recycling would not have a significant reduction in carbon emissions. This is because, surgical devices need to undergo sterilization before they can be recycled. The sterilization process is one of the main impact factors for surgical devices.

Conclusion: Changing the stapler from battery-powered to manual will reduce the carbon footprint significantly. However, it is important to ensure such design principles do not compromise patient safety, usability and reliability of the device, and surgical workflow. Circular strategies of surgical devices, particularly those focussing on closing the loop are not always advantageous from an environmental perspective. This is because, sterilization is required before such devices can be recycled or reused, which may sometimes have high environmental impact.

3.04.P-We038 LCA Analysis of Circular Economy Business Models: A Case Study on Heat Pumps Materials Recycling and Reuse

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Background and Purpose: On the contrary of what has been done with batteries and solar panels, the debate over resource efficiency in the heat pumps industry is quite new, and few studies have discussed this topic. To analyze the circularity of heat pumps a key aspect is the business model (see for example PSS alternatives).

Methods: Two scenarios of introducing circularity in the heat pump sector are analyzed:

1. Introducing circular design practices in the design of domestic heat pumps;

2. Introducing service based business models or PSS (Product Service System) to increase the circularity of heat pumps

The two scenarios are analyzed by means of life cycle assessment (LCA). Different refrigerants and components will be taken into consideration and indexed on their circularity with three approaches:

- Material Circularity Indicator (MCI) by the Ellen MacArthur Foundation [1];

- The Circularity Index (CI) developed by Cullen (2017) [2];

- The Product environmental Footprint (PEF) formula for circularity [3].

Results: The results will be calibrated against the report “A consumer and supply chain analysis on the circularity of heat pumps : investigating the potential implementation of a circular business model” realized by the university of Utrecht in collaboration with Eneco [4].

Conclusions: The paper will brake down the domestic heat pump plant and answers the following questions: which criteria and materials have to be selected in the design phase to reduce HP impact, specifically in the end of life phase, and increase their circularity? which components can be recycled at a reasonable cost and in an economic efficient way? What is the more convenient business mode by the point of view of environmental impact and economic performance for heat pumps?

[1] Ellen MacArthur Foundation, “Material Circularity Indicator (MCI) Methodology,” 2019. [Online]. Available: https://emf.thirdlight.com/link/3jtevhlkbukz-9of4s4/@/preview/1?o. [Accessed 18 April 2023].

[2] J. Cullen, “Theoretical Benchmark or Perpetual Motion Machine?,” Journal of Industrial Ecology, 21, pp. 483-486, 2017.

[3] Schrijvers, D. L., Loubet, P., & Weidema, B. P. (2021). To what extent is the circular footprint formula of the product environmental footprint guide consequential?. Journal of Cleaner Production, 320, 128800.

[4] Schrijer, R. (2024). A consumer and supply chain analysis on the circularity of heat pumps: investigating the potential implementation of a circular business model (Master’s thesis).

3.04.P-We039 Examination of Recycling Processes for Metallized Polymer Foams Using Life Cycle Assessment

Pauline Langbehn, iPoint-systems gmbh; Julius EikGrimmenstein, TU Bergakadmie Freiberg; Maria Dos Santos, iPoint-systems gmbh.

Currently, research into new materials and alternative methods to established processes is critical. For example, metal foams, metallized polymer foams and porous metals are being considered for a variety of applications. In particular, their outstanding weight-to-stiffness ratio and low density play an important role. Their efficient heat transfer properties make them ideal as heat exchangers for power electronics in the mobility sector.
In addition to the physical properties, the aspect of sustainability has to be considered when developing metallized polymer foams. Therefore, the recycling possibility were analyzed and examined in this study. Four recycling process routes with different processes and pre-treatment methods are examined in order to optimize the recycling process. Additionally, this study also analyzes energy consumption and examines the relationship between energy consumption and recycling outcomes. To ensure a sustainable approach, Life Cycle Assessment (LCA) was selected as the methodology to evaluate the environmental impacts of recycling. Therefore, four different recycling paths are examined aiming to take environmental aspects into consideration when deciding about the most suitable recycling technique for metallized polymer foams.
To record the data, internal and external performance measurements were used to determine the comminution energy used per ton of material. Furtermore, the pureness of the recycled decoated copper is of importance. Only pure decoated copper is considered unproblematic for reuse as impure copper with polymers could contaminate further processing. The result of the processes is analyzed using various methods to determine the degree of decoating for getting the amount of pure copper released at the end of the

recycling. The data collected throughout the recycling processes is used for the LCA, which is carried out by using an LCA-expert software. After conducting the LCA the four different recycling process routes are compared to each other. The method enables a hotspot analyses which allows recommendations for action. A decision on the most suitable recycling path is made by taking the Global Warming Potential (CO2-eq.), the quality of the output and energy consumption of the specific recycling processes into account.

3.04.P-We040 Agro2Circular Circular Solution Life Cycle Assessment Approach

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Background and purpose: Agro2Circular (A2C) is an EU project whose solution will upcycle residues from the agriculture (including fruits, vegetables, and multilayer plastics) and food packaging into valuable products. The aim of the presentation is to describe the LCA approach of a territorial agri-food industry circular solution. The goal is not to demonstrate the LCA results, but rather to describe the process from an LCA practitioner point of view.

Methods: An LCA will be carried out together with qualitative evaluation of the suitable metrics of circularity. The A2C demonstrator is a regional circular economy system to be located in Murcia, Spain. In the A2C project, the circularity will be evaluated qualitatively by setting up a circularity monitoring framework compiled from the existing scientific literature. This presentation does not describe the circularity monitoring in detail but aims to present the principles of the framework drafting process.

Results: The characteristics of the A2C LCA approach and challenges are presented. The characteristics contain topics such as selection of the studied streams from multi-input and output options, system boundary definitions, data collection strategy and joining the agri-food and plastic chains. Observations and challenges of conducting a complex, circular and multi-input and output system LCA are described in the presentation.

Conclusions: In the Agro2Circular project, the environmental sustainability of a territorial circular agri-food and plastic systemic solution in Murcia will be evaluated using LCA method. The LCA of the A2C circular solution is complex, and it needs to address the following aspects: multi input options (agri-food waste) and multi output product options, demo unit thinking that contains unit processes which flow from one demo to other, crossing of the two waste chains, analysing if the A2C output changes the characteristics of the final B2C product, and how to compare the novel A2C products with conventional ones finding suitable LCI data. In the presentation, data gaps and improvement methods of such complex regional LCA will be proposed.

3.04.P-We041 Business Model Lca Applied to a Product as a Service Model: An Electrolux Group Pilot

Albert Norin, Chalmers University of Technology; Erik Reenbom, Chalmers University of Technology; Stefano Zuin, Electrolux Italia SpA; Monica Celotto, Electrolux Italia SpA; Ana Carolina Bertassini, Chalmers University of Technology.

The Circular Economy (CE) concept aims to create value for society and the economy while reducing environmental impacts, whereas Life Cycle Assessment (LCA) is a recognized methodology for assessing the environmental load of a process or product. Thereby, a combination of CE principals and the robustness of LCA has potential for strengthening available CE strategies, for instance Product as a Service (PaaS). This work presents a business model (BM) LCA method applied to Electrolux appliance-as-a-service pilot in Sweden, an Electrolux Group program enabling customers to pay for the usage of its various appliances rather than owning them (rental model). The BMLCA integrates monetary flows with material and energy flows to capture the impacts of BM. Here, the rental and sale model of Electrolux air purifier were compared through the BM LCA method to highlight the main economic and environmental hotspots of two different BM. A global supply chain was considered for the air purifier, while the use of product was modelled in Sweden. The life cycle impacts were calculated according to the ReCiPe 2016 v1.03, midpoint (H) method, and Ecoinvent v3.10 datasets were used through Open LCA software. Results showed that rental model has a lower impact normalized per amount of generated profit, when compared to the sale model in almost all impact categories. For instance, there is a potential reduction of 10% for the rental compared to the sales model for the climate change impact. Also, the contribution of air purifier's life cycle stages to various impact category differs from sale to rental model. The product assembly has the larger contribution to almost all impact categories for sale model, while for rental model the filter assembly and transports become more relevant. The reason for this is that the different models require different flows of air purifiers to achieve the same profit margin. Indeed, the sales model requires more air purifiers while the rental model requires more filters to be changed regularly. Sensitivity analysis also showed that both models are strongly affected by product-related parameters (e.g., expected lifetime of air purifiers) and by economic-related parameters (e.g., rental and sales price). To conclude, the study identified the challenges for current and future research directions to promote the development of BMLCA in CE strategies from Electrolux perspective.

3.04.P-We042 Reviewing the Final Phase of Offshore Wind: A Life Cycle Perspective

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Background and purpose:

As the transition to renewable energy is expected to accelerate over the coming decades, offshore wind is supposed to play a crucial role. However, this upsurge in wind farm installations coincides with the ageing of early offshore wind farms. With few precedents in decommissioning and the nescience of the end-of-life (EOL) supply chain, the risk of valuable material losses is pressing. Moreover, life cycle assessment (LCA) studies are often lacking in decommissioning and EOL phase information, likely missing out on critical details and opportunities. This research aims to bridge this knowledge gap by focusing on the EOL and decommissioning challenges, setting the stage for a detailed LCA and addressing unexplored aspects from derived recommendations.

Methods:

Through a systematic review of existing LCA literature, significant gaps were identified, particularly in the treatment of the decommissioning and EOL phase. This review highlights crucial shortcomings and provides the necessary recommendations to be integrated into offshore wind LCA studies. Pinpointing these underrepresented aspects sets the basis for a detailed assessment of a specific case study, linking supply chain bottlenecks with the proposal of circularity metrics, suitable for the offshore wind sector.

Results:

Several key areas were revealed, with just 6 in 16 studies having access to primary data, only 2 with a transparent dismantling and decommissioning description and even though all studies include a form of carbon footprint, other impact categories or circularity metrics are rare to non-existent in the selected literature. Furthermore, this review concludes that a better characterization of the temporal scope and learning effects as well as accurate material flows at the end of life should be imperative. These aspects are essential for refining the LCA methodology and improving their relevance to the sustainable management of future offshore wind energy projects.

Conclusions:
Finally, this research emphasizes incorporating circular economy principles into the EOL phase of the LCA framework. These principles can align offshore wind decommissioning and its waste treatment processes with circular economy goals and economic considerations. These findings are therefore essential for policymakers and industry stakeholders, offering a clearer path to enhance the environmental sustainability of offshore wind projects without overlooking economic and legislative aspects.

3.04.P-We043 Study on the Decarbonisation Potential of Hydrogen Implementation in Float Glass Industry using Life-Cycle Assessment (LCA

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Climate change devastating impacts are no longer arguable. The increasing demand for products from various industries means more severe impacts on the environment. Glass manufacturing, being a key industry in human civilisation history, is one of the highest energy-consuming industrial activities. This high energy demand is attributed to the high energy needed to melt the raw materials usually attained by burning fossil fuels, such as natural gas. Several methods are being proposed to decarbonise the glass industry like carbon capture, Biofuels, electric melting or hybrid fuels such as hydrogen. According to the stakeholders, hydrogen presented itself as the most preferable candidate due to the cost, unstable supply and disruptions involved with the other alternatives. However, hydrogen generation is not always environmentally friendly depending on the type of energy used. Thus, switching to hydrogen without exploring the overall life cycle might do more harm than good. Life-cycle assessment (LCA) has been utilised to assess and compare the environmental impacts of using different sourced hydrogen to that of natural gas. One kg of float glass was chosen as the declared unit for this LCA, with a case study using natural gas and two other studies using green and grey hydrogen. With the production process being the main focus, a cradle-to-gate model without transportation has been used as the system boundary. Global Warming Potential (GWP), Ozone Layer Depletion (ODP) and Abiotic Depletion (AP) were chosen as the indicators for the impact assessment based on CML IA baseline V3.08 and SimaPro 9.4 was used for the calculations. The primary data for combustion were obtained using FactStage software relying on fuel composition and temperature settings, while upstream data were from EcoInvent 3.8. Early results suggested that hydrogen is a promising candidate for GWP with a reduced amount of carbon dioxide released upon combustion, especially green hydrogen. However, the other impact indicators did not all favour hydrogen due to the environmental effects of hydrogen production. Further analysis in this research will examine the effects of different routes of producing hydrogen on float glass production emissions. This will provide significant insights to assist with the decarbonisation of the glass industry by providing a holistic view of the float glass life cycle. Thus highlighting the hotspots where adequate measures should be implemented to reduce emissions.

3.04.P-We044 Using Lca for Evaluating Hotspots and Circularity Strategies in Semiconductor Manufacturing

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Modern society leans heavily on technological advancements, which are enabled by the semiconductor industry. Semiconductor manufacturing, however, requires considerable amounts of energy and water, making it both a very resource and emission intensive industry. Following Moore's Law, integrated circuits (ICs) are getting ever smaller and more complex, thus, leading to more defined and demanding manufacturing processes [1]. Therefore, each generation of semiconductors is creating heavier environmental impacts. So far, semiconductor manufacturing has been assessed e.g. in regard of greenhouse gas (GHG) emissions, mineral and metal resource use, and water use [1], while the circularity aspect has not gained much attention.

This study aims to identify environmental hotspots in the value chain of semiconductor manufacturing, whilst having special focus on the circularity strategies in the manufacturing stage. Life Cycle Assessment (LCA) is used to evaluate environmental burdens, and to examine potential impacts of more circular processes, for instance the recovery of critical raw materials. The impacts of using alternative raw materials for the manufacturing processes are also explored, since for fulfilling the requirements of more advanced semiconductors, new materials need to be found, e.g. to replace copper as an interconnect.

As a result of the LCA study, the value chain of the Finnish semiconductor ecosystem and its impacts are mapped. Additionally, the process steps with potential for improvement are pointed out so that industry actors can use tangible measures to minimize their environmental impacts and optimize their processes for more circular direction. Finding ways to increase circularity throughout the value chain is essential since it improves the overall sustainability of wafer processing significantly. The study contributes to a Finnish roadmap aimed at increasing circularity in the semiconductor industry, identifying hotspots and areas of improvement, and focusing on activities where Finnish companies can make an impact.

[1] Kuo T.-C., Kuo C.-Y., Chen L.-W. 2022. Assessing environmental impacts of nanoscale semi-conductor manufacturing from life cycle assessment perspective. Resources, Conservation & Recycling 182:106289

3.04.P-We045 Designing a Circular Packaging System in Light of PPWR.

Pieter Callewaert, NORSUS Norwegian institute for Sustainability Research.

The Plastic Packaging Waste Regulation (European Parliament and Council, 2024) aims to increase both the collection of Plastic Packaging Waste (PPW) and the use of recycled plastic. Contact sensitive packaging for example, faces minimum requirements related to recycled content (25% by 2040). When designing the new system for PP packaging in Norway, how much attention should contact sensitive packaging receive? Should we use recycled plastics there at all? And if so, how should we do this?

The study analyses the environmental impact of three circular strategies. While the first strategy uses recycled plastic in non-food applications only, the other two strategies supply recycled plastic to contact sensitive applications and hence, they comply with the targets set by the PPWR. Whereas the former uses conventional recycling technology to achieve the targets, the latter uses a strict source control system with additional decontamination processes to accomplish higher recycled content values than required (up to 80%). For each strategy, the virgin PP need is first simulated over 16 years (from 2025 to 2040) by using a dynamic MFA approach. Afterwards, the mass flows are used as the basis for the LCA.

Preliminary results show that the first strategy has the highest environmental impact. When targeting non-food applications only, the system faces an increased stock of unused recycled material, mainly due to the increased recycling rate from 2025 to 2030, as demanded by PPWR. Furthermore, the second strategy also results in unused recycled material, however, considerably less than the first strategy. The lowest environmental impacts are observed for the third strategy that, unlike the other strategies, manages to use all recycled material.

This study shows that there is a need to target contact sensitive packaging applications to avoid unused recycled PP. However, this should happen in line with increasing recycling rates, meaning that additional processing steps are justified only when material uptake is threatened. With sufficient demand (including from other sectors), one should focus on increasing the amount of plastics being recycled.

EUROPEAN PARLIAMENT AND COUNCIL 2024. European Parliament legislative resolution of 24 April 2024 on the proposal for a regulation of the European Parliament and of the Council on packaging and packaging waste, amending Regulation (EU) 2019/1020 and Directive (EU) 2019/904, and repealing Directive 94/62/EC.

3.04.P-We046 Driving Sustainability in Utility Pole Production: A Circular Economy Approach

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The utility poles industry has seen significant growth due to global population growth, which has raised energy and telecommunication demands. However, this growth has raised environmental concerns, leading to a search for sustainable solutions based on circular economy principles. This project integrates Life Cycle Assessment and Cost, facilitating a comprehensive analysis to determine the most cost-effective and eco-friendly option. Efforts are now focused on evaluating different pole compositions: Option A with post and pre-consumer waste and virgin reinforced materials, Option B with post and pre-consumer waste and recycled reinforced materials, and Option C with lower percentages of post and pre-consumer waste, and higher percentages of recycled reinforced materials.

The International Standard Rules, ISO 14040-44 have been used to evaluate the environmental impacts. While the project's overarching objective is sustainable pole production, our current focus is on evaluating the impacts of different compositions intended to be used in pole manufacturing. The study followed a "cradle to gate" approach. The declared unit was the production of 1 kg of compound. The environmental assessment was evaluated in SimaPro software and the background data was collected from the EcoInvent. The ReCiPe 2016 method (Midpoint, Hierarchist) was employed.

Option A had the highest environmental impact when compared to the remaining proposed compositions. On the opposite, Option B presented the lowest environmental impact in all impact categories. This outcome underscores the advantages of using recycled over virgin reinforced materials and the use of waste over recycled material. Regarding the economic assessment, internal and external costs were evaluated, and the results were consistent with the environmental ones.

In conclusion, this study underscores the influence of material composition on environmental performance and costs. It suggests that incorporating recycled material brings advantages compared to virgin material, and the use of waste is the best option. This innovative pole aims to promote the circular economy approach as recommended by the European Commission.

This research was supported by the Innovation Pact "Agenda Mobilizadora para os Plásticos Sustentáveis" by the Consortium "Sustainable Plastics", co-financed by NextGenerationEU, through the "Business Innovation Agendas" investment from the Recovery and Resilience Plan (RRP) from European Commission.

3.05 - Holistic Life Cycle Sustainability Assessment

3.05.T-01 Holistic and Integrated Life Cycle Sustainability Assessment: Background, Methods and Results from Two Case Studies

Walther Zeug, Helmholtz-Centre for Environmental Research (UFZ).

To address the challenges of the current societal-ecological crisis, we developed an integrated sustainability framework and an implemented and validated innovative method of Holistic and Integrated Life Cycle Sustainability Assessment (HILCSA). HILCSA allows an integrative (ecological, economic, social in one method) and holistic (transdisciplinary and critical) sustainability assessment based on about 100 social, ecological and economic qualitative and quantitative indicators addressing 14 out of 17 SDGs, in order to analyze synergies, trade-offs and hotspots of production and consumption systems in the bioeconomy and beyond. This method is fully software implemented in openLCA and using the Ecoinvent/SoCa database.

We applied HILCSA in two case studies in context of bioeconomy. In the first case, a comparison of wood building products with conventional steel beams showed that renewable bio-based construction materials can have a better holistic sustainability than fossil-based products for nearly all indicators, by less stressing the environment, having a less negative impact on society and being economically more efficient. However, fossil-based components of such as phenolic resin are main contributors of negative impacts and should be reduced and replaced. In the second case, we compare liquid biofuels as a drop-in alternative to substitute fossil fuels in the transport sector, showing some contributions to the SDG but significant sustainability risks of such biofuels in terms of land and water use, energy efficiency, working conditions and maintaining problematic global supply chains.

Through this quantitative and qualitative sustainability assessments we identify synergies and hot-spots of bioeconomy production systems production on a detailed and aggregated level. Common problems are the very hard planetary boundary of land and water availability limiting renewable resource and goods production, as well as maintained global socio-economic problems in supply chains when bioeconomy does not go in hand with a societal-ecological transformation. It can also be concluded that renewable resources should be used primarily for material use and only energetically at the end of a cascading life cycle.

HILCSA can provide comprehensive information and decision basis for stakeholders such as politics, society, research and organizations. However, problems and potentials in method, software and indicator development still need to be discussed in future research.

3.05.T-02 Life Cycle Sustainability Assessment based Strategy for Safe and Sustainable by Design Advanced Materials

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The European Green Deal, the Chemical Strategy for Sustainability, and the Zero Pollution Action Plan envision a transition towards a toxic-free environment through developing Safe and Sustainable by Design (SSbD) chemicals and materials. To support its implementation, the European Commission (EC) published its Recommendation for establishing a European assessment framework for SSbD, accompanied by the EC Joint Reserch Centre's SSbD framework. To operationalize this framework, the H2020 SUNSHINE project has developed a tiered SSbD assessment methodology, which was tested in a suite of advanced multi-component nanomaterials. This approach enables the assessment of safety and sustainability aspects at each stage of product development from a lifecycle perspective. Tier 1 consists of a qualitative self-assessment questionnaire targeted at the early R&D and product optimisation stages of the innovation process. The outcome are 'hotspots' of safety and sustainability along the lifecycles of the target materials. Tier 2 performs in-depth analysis of these concerns by applying the established quantitative Chemical Safety Assessment, Lifecycle Assessment, Lifecycle Costing, and Social Lifecycle Assessment methodologies. This results in a full Life Cycle Sustainability Assessment of the investigated materials/products prior to their release on the market. This tiered approach was applied to four SUNSHINE industrial case studies in an iterative process. The results show that Tier 1 significantly supported the early stages of material development by identifying potential safety and sustainability challenges already during the R&D when changes to the production process were still feasible and affordable and there was still flexibility in selecting different design options. Tier 2 was instrumental in validating the Tier 1 results and targeting the identified 'hotspots of concern' in more detail later in the innovation process when more data were available. This has demonstrated the added value of the SUNSHINE SSbD approach to enable companies to assess the safety and sustainability performance of their products in an easy, targeted and therefore affordable manner. This can have a significant impact on making these industries more competitive on the market while leading the design of more environmentally friendly nanotechnologies of high societal and economic benefit.

This work has been carried under the SUNSHINE project grant agreement No 952924

3.05.T-03 A Holistic Sustainable-by-Design Approach Applied to a Novel Solid Oxide Electrolysis Cell Stack

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Green hydrogen is expected to play a key role in the decarbonisation of the energy sector. Nevertheless, achieving product sustainability requires a multifaceted approach that tackles all phases of the process and considers the different sustainability dimensions. In this regard, a holistic sustainability assessment of hydrogen-related products is needed, enabling a versatile and integrated interpretation of various technoeconomic, environmental, social, criticality and circularity indicators.

This work proposes a novel methodological framework oriented towards the development of sustainable-by-design hydrogen-related products based on the implementation of Life Cycle Sustainability Assessment, while addressing additional relevant aspects such as raw material criticality and underdeveloped topics such as end-of-life management. Furthermore, the proposed holistic sustainable-by-design approach is illustrated through the case study of a novel Solid Oxide Electrolysis Cell (SOEC) stack.

Raw material criticality was assessed through the SH2E criticality indicator, finding a remarkable decrease when compared to a reference SOEC stack. Additionally, an end-of-life simulation model was built using Aspen Plus to reduce the input of virgin raw materials by implementing a closed-loop recycling strategy, which led to a promising circularity performance. Environmental and social life-cycle indicators were estimated using the Environmental Footprint and PSILCA methods, respectively. Electricity, chromium, reinforced steel and gadolinium oxide were identified as environmental hotspots. According to a bottom-up cost analysis approach combined with Design for Manufacturing and Assembly, materials and equipment were found to account for more than 70% of the levelised cost of the stack.

Overall, the proposed approach succeeds in enabling a holistic and multi-dimensional sustainability assessment of hydrogen-related products, supporting their commercialisation and deployment as sustainable-by-design solutions. Finally, it should be acknowledged that this work has been carried out in the context of the NOUVEAU project, which has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement N°101058784. Views and opinions expressed are however those of the authors only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them.

3.05.T-04 Integrating Safety and Sustainability for the Assessment of Bio-Based Solutions for Art Restoration: The GREENART Approach

Martina Menegaldo, Ca' Foscari University of Venice; Elisa Giubilato, GreenDecision s.r.l.; Maria Rachele Sesterzi, Ca' Foscari University of Venice; Lisa Pizzo, GreenDecision s.r.l.; Alex Zabeo, GreenDecision s.r.l.; Elena Badetti, Ca' Foscari University of Venice; Elena Badetti, Ca' Foscari University of Venice.

The GREENART (GREen ENdeavor in Art ResToration) project, funded by the HORIZON Europe Programme, proposes new advanced materials and chemicals to preserve, conserve, and restore Cultural Heritage. The main objective is to develop safe and efficient solutions, including gels, cleaning fluids, protective coatings, consolidants, packaging materials, and sensors, for the corrective and preventive conservation of cultural heritage. These solutions utilize low-impact materials derived from renewable natural sources or recycled waste. In this context, and in view of achieving the goals of the EU Green Deal, a holistic approach should be taken to identify solutions for safer and sustainable restoration. Building on the NANORESTART Framework and the new Framework for Safe and Sustainable by Design (SSbD) chemicals and materials from the European Commission, GREENART proposes a stepwise three-stage approach to assess the safety and sustainability performance of its innovative solutions throughout their entire life cycle, providing product developers with a tool for informed decision-making. The primary goal of this approach is to provide a systematic guidance for the design of safer and more sustainable products. Stage 1 consists of the hazard assessment of GREENART ingredients and formulations. Stage 2 includes a Screening sustainability assessment and, finally, in stage 3, Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) are employed to estimate environmental and economic impacts along the life cycle of the most promising innovative solutions, comparing them to currently existing solutions. The main challenge in assessing innovative solutions during the design phase is integrating a quantitative assessment, as most products are at a low Technology Readiness Level (TRL) and are still at the laboratory or pilot scale. Currently, efforts are focused on implementing a framework for screening sustainability assessment throughout the entire lifecycle of GREENART products. The implementation of a Life Cycle Safety and Sustainability Assessment within the GREENART project is aimed at translating and testing the efficacy of the SSbD framework in the specific professional sector of art restoration and is expected to contribute to the development of criteria for chemicals and advanced materials designed for the conservation of cultural heritage.

EMPTY?

3.05.T-05 Integrating Life Cycle Assessment with Life Cycle Cost Analysis for Automotive Polymer Injection Mould Production: A Parallel Approach

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The integration of Life Cycle Cost (LCC) and Life Cycle Assessment (LCA) methodologies allows us to consider economical and environmental impacts throughout the mould's lifecycle. Portugal's mould industry exports 80% of their production to 93 markets, ranking 8th global. Based on this, the INOV.AM agenda aims to boost Portugal's competitiveness in this 23-billion-dollar value market, by developing an innovative hybrid mould using Additive Manufacturing (AM). The present work aims to analyse the environmental and economic impacts of producing a polymeric mould, through LCA and LCC. Sharing the same structure and declared unit, the LCA and LCC analyses follow ISO 14040-44 standards, studying a cradle-to-gate approach. The selected declared unit was the production (and validation) of one mould, weighing 428 kg. The analyses were conducted using SimaPro v9.6 software, with primary data for the inventory from a mould production company while secondary data from the Ecoinvent database (v.3.10), with mass allocation per cutting unit ("Cut-off, U") and, where applicable, data-specific to Europe ("RER"). The ReciPe Midpoint (H) method was employed, applying the Pareto rule. The LCC analysis was calculated by combining the external and internal costs of the mould production, however, costs related to infrastructure, human resources and maintenance were excluded. Regarding the LCA analysis, the environmental categories Terrestrial Ecotoxicity, Marine Ecotoxicity, and Human Carcinogenic Toxicity, accounted for 86% of the total impacts, being the mould production stage identified as being responsible for 99% of the total environmental impacts. This significant impact is predominantly attributable to the input of steel, which emerges as the primary contributor. Through a comprehensive analysis of LCC, it was possible to ascertain that the total cost for the mould production process was 3.19E+03 euro, whereby the internal costs correspond to 1.75E+03 euro (55%) and the external costs to 1.45E+03 euro (45%). Like in the LCA analyses, the mould production phase is responsible for 93% and 95% of all the economic impacts, respectively. This is primarily due to the acquisition of raw materials, specifically steel. By combining LCA and LCC methodologies, the research promotes both environmental and economic efficiency, fostering sustainable awareness among stakeholders and encouraging the reduction and substitution of raw materials within a circular economy framework.

3.05.P - Holistic Life Cycle Sustainability Assessment

3.05.P-Mo033 Life Cycle Assessment of Alternative Tree Systems

Elsa Webb, Cranfield University; Paul Burgess, Cranfield University; Georgios Pexas, Cranfield University.

Establishing alternative tree systems has become a widely accepted method to increase carbon sequestration and mitigate impacts associated with climate change. These systems thereby also contribute towards global sustainable development and Net Zero targets. However, due to the wide diversity of alternative tree systems and their context-specific multifunctionality, there is a significant gap in understanding the implications for sustainability through a holistic life cycle sustainability approach (LCSA).

The study proposes a novel multi-step approach to investigate the potential benefits and negative implications of alternative tree systems implemented in diverse spatiotemporal contexts through an LCSA perspective. This involves the following four distinct phases:

1. Co-definition, with stakeholders, of the goal and scope of the LCSA to address the wide range of alternative tree system products and services, system boundaries, and spatiotemporal variability across various environmental and socio-economic metrics.

2. Co-design, with stakeholders, of a comprehensive life cycle inventory. This could involve focus groups and a Delphi approach to understand stakeholder sustainability priorities and capacity for primary data collection/provision to support the development of a comprehensive, holistic LCSA.

3. Development and use of a comparative LCSA of alternative tree systems across a range of landscapes. This research will apply the framework using data from mature sites and pilot studies across England.

4. Stress-testing of LCSA framework with projected climate-change and macroeconomic scenarios, and spatiotemporal uncertainty analysis to quantify the robustness of outputs and investigate sustainability synergies and trade-offs.

The study aims to generate novel insights into the sustainability impact hotspots of alternative tree systems implemented across a range of geographical settings and temporal scales. The findings of this study will thereby aim to facilitate decision and policymaking at different scales. Firstly, for a more effective management and ultimately, for the strategic expansion of such complex systems.

3.05.P-Mo034 Methodological and Reporting Gaps in Life Cycle Sustainability Assessment: A Systematic Literature Review

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Background and Purpose: Our world faces significant challenges in terms of environmental sustainability, economic feasibility and social equity. Despite the imperative need and the notable progress in addressing the above dimensions individually, the holistic approach of combining the three pillars of sustainability in a life cycle perspective, known as Life Cycle Sustainability Assessment (LCSA) is limited.

Methods: This work is a systematic review of existing methodologies of LCSA in various sectors and case studies, following the PRISMA protocol for literature review reporting in Scopus database. The results are limited to articles and reviews since 2000 yielding 242 papers after applying eligibility criteria.

Results: The results indicate a growing interest in LCSA reporting in recent years with the majority of the analyzed papers applying existed methodologies across various sectors. Around half of the papers under study are employing an integrated approach in LCSA reporting while the remaining are separately addressing the three sustainability pillars without aggregating the results. Our meta-analysis also identifies the most frequently assessed environmental, economic and societal indicators and details the methodological approaches used in cases of aggregated results. Additionally, we outline the system boundaries defined in each LCSA methodology used or proposed revealing that the life cycle perspective is not consistently considered in LCSA studies. Another interesting point of the study is that there is little to no progress in linking the LCSA results with commonly accepted sustainability indicators such as the Sustainable Development Goals (SDGs) and the Planetary Boundaries (PBs). This inhibits the "absolute" sustainability assessment raising comparability issues between LCSA results. Through this meta-analysis, we identify all the weaknesses and threats as well as the strengths and opportunities (SWOT analysis) regarding the implementation of LCSA.

Conclusions: LCSA provides a comprehensive assessment and serves as a valuable decision support tool to governments and industries. However, the lack of standardization and poor data quality and availability pose a restricting factor for its widespread adoption. This work concludes on providing future directions on improving the LCSA framework resulting in its broad implementation with the overarching goal of developing, based on existing knowledge, a holistic LCSA methodology.

3.05.P-Mo035 Connecting "Safe and Just Operating Space" with Life Cycle Sustainability Assessments of Energy Technologies: A Case Study on Wind Power Production in Sweden

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A transition towards renewable energies is essential to reach climate neutrality by 2050. However, such transition can have side effects on other environmental, social, and economic aspects (e.g., land use change, mining of rare earth metals). Until now, life cycle sustainability assessment (LCSA) studies have focused on relative sustainability which compares similar products to each other, determining which one performs better. In contrast, the concept of absolute sustainability evaluates whether a product supports sustainability in absolute terms, allowing current and future generations to have their needs met within the planet's biophysical limits.

This study addresses the need for broader sustainability assessments in the energy sector by integrating the concept of "safe and just operating space" (SJOS) with LCSA. A set of indicators covering environmental, social, and economic aspects of energy production systems and allowing the integration of SJOS with LCSA were identified based on a literature review. The indicators were tested in a case study assessing the sustainability of electricity production from a wind farm located in Jädraås (Sweden) from cradle-to-grave. The distance-to-target multicriteria decision analysis method NR-TOPSIS was used to compare the performance of this wind farm in relation to external reference points. The reference points were based on ideal (minimised impacts fitting within the SJOS) and non-ideal conditions ("business as usual" practices).

15 indicators were successfully applied in the case study and shown as relevant to the wind energy sector. These indicators allowed the evaluation of environmental impacts based on the planetary boundaries. The economic sustainability was assessed using six indicators including resource efficiency, supply risks, and energy supply reliability. Finally, seven indicators including local perspective, human health risks, labour conditions, and local communities' access to resources were used to quantify social impacts.

Overall, this study shows the importance of connecting the SJOS with LCSA to perform comprehensive sustainability assessments of energy technologies. The indicators can be used to compare different energy systems in relation to external reference points adjusted to the specific purpose and context of the study. Further research should focus on determining absolute social and socio-economic sustainability to establish a consensus similar to the planetary boundaries.

3.05.P-Mo036 Analyst | Multi-Actor Approach Roadmap for Implementing an Integrated Holistic Impact Assessment to Accelerate Safe and Sustainable Design (SSbD) Acceptance in the Plastic Value Chain

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Plastic pollution is one of the most serious threats to humanity. In response, the European Union is promoting an approach to guide the innovation of materials like Polyvinyl Chloride (PVC) towards a safer, circular economy. In this context, the ANALYST project emerges with the aim of accelerating the transition towards a safer and more sustainable plastic value chain. The project also seeks to enhance the existing knowledge of the Safe and Sustainable by Design (SSbD) framework. The success of the project depends on the development of a multi-actor approach roadmap, which will be detailed here.

This study employs the multi-actor roadmap as a tool for collaborative strategic planning to guarantee the success of the project, and includes 6 key stages: First, detailed implementation guidelines offer clear instructions and success metrics, while continuous monitoring facilitates ongoing enhancements. Tailored training programmes, the second component, boost team capabilities. Thirdly, a small-scale pilot test involving industrial organisations (multi-actors) from the PVC value chain is conducted to identify issues with the integrated approach. Feedback from this test and stakeholder consultations refines the approach. Lastly, the findings and the validated roadmap are disseminated to promote adoption and underscore the benefits, aiming to broaden its usage and support.

To start, stakeholders will receive guidelines to test the innovative integrated approach. Through tailored training, they will examine conventional materials that incorporates the 4 dimensions (health, environmental, economic, and social) aligned with the SSbD framework. Subsequently, these stakeholders will specify the requirements they wish to evaluate to foster innovations. Following this, insights and actions will be gathered to provide a comprehensive analysis of lessons learned, gaps, and risks. This analysis will serve to enhance both the integrated approach and the SSbD framework, while also providing critical feedback to develop strategies for extending the SSbD framework beyond the project's duration. It is important to mention that the proposed roadmap is not static, needing several iteration cycles to fully develop the final vision.

This roadmap is called to be a pivotal tool in ensuring the success of the ANALYST project, and involving various stakeholders, that will play a crucial role in facilitating the transition towards a safer and more sustainable plastic value chain.

3.05.P-Mo037 Life Cycle Sustainability Assessment of Laminated Strand Lumber in the Spanish Woodworking Sector: Integrating Economic, Environmental, and Social Dimensions
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This study analyses the sustainability performance of Laminated Strand Lumber (LSL) in the Spanish woodworking sector, focusing on its economic, environmental, and social dimensions. To this end, a case study has been selected in the context of the CALIMERO project. The main objective is therefore to address some of the challenges facing the woodworking sector in Spain, including the need for sustainable alternatives and practices due to social risks such as job losses and health and safety issues, particularly related to toxic risks. With regard to environmental concerns, the assessment is focused on including in the assessment the impact of volatile organic compounds emitted during wood processing.

The assessment follows an attributional life cycle approach, integrating Life Cycle Assessment (LCA), Social LCA (S-LCA), and environmental Life Cycle Costing (LCC) methodologies. While the environmental analysis evaluates indicators recognized by the Product Environmental Footprint guidelines, the impact on the local community is analyzed in terms of job creation potential, using the Social Hotspot Database for data collection. For the economic dimension, net present value, levelized cost of production and cost of CO2 emissions based on the European Emissions Trading Scheme (ETS) are considered. The study takes a cradle-to-gate approach, covering the stages of forestry, wood transport to the plant and the manufacturing process of LSL. This case study serves as an example of how the three dimensions of sustainability can be integrated, and highlights the methodological challenges involved.

3.05.P-Mo038 Approaching Holism – Aligning Environmental LCA and Social LCA in the Context of Circular Plastic Packaging Value Chains
Alex Newman, The University of Sheffield; Ewen Rondon, IPC Centre Technique Industriel de la Plasturgie et des Composites; Rachael Rothman, The University of Sheffield.

As part of the EU funded BUDDIE-PACK project the need for a holistic approach to lifecycle sustainability assessment emerged, targeting the parallel evaluation of environmental, economic, and societal impacts associated with reusable plastic packaging. Such insights offer valuable support within the continued development of sustainable and circular strategies for the adoption of reusable plastic packaging in the food and cosmetic/personal care sectors.

However, currently, no formal standards exist around the harmonisation of the three 'pillars' of sustainability (environmental, economic, and societal). Often, the application of assessment types in isolation results in misaligned system boundaries and conflicting inventory data, significantly reducing the practitioner's ability to accurately evaluate burden shifting. This issue is exacerbated by social LCA's (S-LCA) comparative lack of standardised or broadly adopted methodologies, harbouring several diverging schools of thought, primarily around impact characterisation. Consequently, for meaningful and insightful evaluation of holistic sustainability profiles, it must be demonstrated that the pillar's methodologies can be efficaciously harmonised.

Cognizant of these factors, a UNEP and SETAC inspired methodology has been developed, through which S-LCA is aligned with LCA and LCC studies. In this, a reference scale approach to social impact characterisation has been adopted, avoiding the issues around uncertainty and highly complex social structures associated with impact pathway-based alternatives. Furthermore, it is demonstrated through an initial screening assessment that UNEP and SETAC's proposed stakeholder groups can be systematically reduced, improving efficiency while adhering to common goal and scope statements. The output from this work is a methodology that demonstrates unified system boundaries and a common life cycle inventory, upon which burden shifting can be comprehensively and repeatably examined across the three assessment types.

S-LCA has augmented LCA and LCC studies through the evaluation of thirteen social indicators covering consumer, worker, and local community stakeholder groups. Six unique use cases are examined, verifying broad applicability to assessments examining reusable plastic packaging in both business to business and business to consumer value chains. From the study, key impact hotspots are identified and targeted for improvement.

3.05.P-Mo039 Model-based Life Cycle Sustainability Assessment (LCSA) for Plastics and Recycled Content
Julia Cilleruelo Palomero, GreenDelta GmbH; Andreas Ciroth, Greendelta; Jonas Hoffmann, GreenDelta GmbH.

Life Cycle Sustainability Assessment (LCSA) combines environmental, social and economic life cycle assessments in what is now thought of as a "full" sustainability assessment. The methodology, however, 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. This research proposes a "Model-based LCSA" with the integration of System Dynamics (SD) and LCA for a wide-range picture of plastic recycling. The research is part of the PRIMUS project, which investigates increasing % recycled content in high value plastic products, funded by the EU. The Stella software for SD and openLCA with ecoinvent for LCA are used to create a Model-based LCSA, where LCA results for the 16 impact categories of EF3.1 are included in the SD model for plastic production and end-of-life stages. The model is investigated over a time frame of 1950-2060 for two distinct scenarios. The base scenario is given by plastic historic and predictive data sources like the Global Plastics Outlook by OECD, and recycled content scenario aims to part from the base case but vary the amount of recycled content in plastic products. In the SD model, external variables such as legislative trends, consumer recycling appreciation, technological

potential of recyclate integration, or availability of recyclates in the market influence the life cycle of plastics.
It can be seen from the model that, to arrive to a high percentage recycled content in plastic products, the market for recyclates has to be able to cater demand. Furthermore, increasing the recycled content up to 90% in plastic products does not stop the increasing rate of plastics available in the world, and consequently plastics in landfill or being littered, or the environmental impacts coming from it, but slows it.

3.05.P-Mo040 Environmental and Economic Impacts In the Poultry Chain After Innovative Microbial Application

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The microbiome application could be a solution to improve broiler production, such as broiler growth and feed conversion efficiency. The goal was to analyze the environmental sustainability of innovative microbial applicated broiler (=Mic-broilers) production in a life cycle perspective, aiming to improve the food chains by microbial interventions.

The primary data were collected from the broiler farms in Italy while the missing data were sourced from ecoinvent and Agri-footprint databases. Cost data was collected from the broiler farms from year 2023. The functional unit was the production of 1 kg broiler live weight (LW). System boundaries are considered from cradle to farm gate, involving the feed production, transportation, and broiler production stages. The significance of feed composition replacement on environmental and costs impacts was analysed with sensitivity analysis. Environmental impact assessment is conducted for global warming, freshwater and marine eutrophication, the human toxicity (cancer and non-cancer) and freshwater ecotoxicity.

The environmental impacts, except for freshwater toxicity, were higher for conventional broiler than Mic-Broilers. This reduction was mainly due to the changed feed composition with lower environmental impacts in the intervention phase. However, as for the cost impacts, Mic-Broiler showed a bit higher cost impacts than conventional broiler mainly due to the more expensive changed feed composition in the intervention phase. Overall, it was found that Mic-Broilers require more food than conventional broilers while achieving a higher weight per animal. Both environmental and cost impacts showed hot spot interrelations as bedding material and feed production had the major impacts during the life cycle of conventional and Mic-Broiler. Mic-Broilers with changed feed composition resulted in lower environmental impacts but higher cost impacts than conventional broiler production. Changed feed composition was the only significant difference between Mic-Broiler and convention broiler production scenarios. Both environmental and cost had all the major impacts during the life cycle of conventional and Mic-broiler with feed, bedding material and operations of broiler house.

The study creates opportunities to find the most critical points to minimise environmental impacts and production costs and add value throughout the life cycle of products and guide the decision-making processes of companies towards sustainability.

Track 4: Sector Focus

4.01 - Life Cycle Assessment of Batteries

4.01.T-01 Carbon Footprint of Electric Vehicle Battery Use Phase: A Model and Application

Hyung Chul Kim, Ford Motor Company; James Anderson, Ford Motor Company.

Background and Purpose: As the electric vehicle (EV) market grows and the demand for longer all-electric range increases, reducing the carbon footprint of lithium ion batteries (LIBs) is becoming increasingly important. Recent life cycle assessments (LCAs) provide more comprehensive analyses for battery carbon footprint than ever before, as more industry primary data become available. However, LCAs have mainly focused on the cradle-to-gate stage, with little or no consideration of the battery use phase, primarily because there is no general agreement on the scope and approach to evaluate this stage. In this study, we aim to evaluate the use phase carbon footprint for EV batteries and compare across battery types and designs.
Methods: We first developed a physics-based model to evaluate energy consumption during the battery use phase. The model allows for estimation of both energy losses during battery charge-discharge cycles and the energy consumption induced by battery mass. Then, we used the model to evaluate the use phase carbon footprint of various LIB designs in the LCA literature based on US average conditions.
Results: Our physics-based model illustrates that the two sources of battery energy usage are incompatible from a methodological standpoint. While the former is determined through the lens of vehicle energy efficiency, the latter is assessed from the viewpoint of vehicle load, i.e., power demand. Literature LCAs often employ these two different viewpoints simultaneously, resulting in double counting. Instead, we provide separate models using the efficiency and load viewpoint consistent with physics principles.
A model application shows that the carbon footprint from energy losses during charge-discharge cycles, e.g. ~5% of energy stored in the battery, is rather homogeneous across battery designs. It is not related to battery size and capacity, although it is a function of EV fuel economy. On the other hand, the carbon footprint induced by battery mass, unsurprisingly, varies depending on battery size (kWh) and energy density (Wh/kg).
Conclusions: This study provides a comprehensive approach to understanding the life cycle carbon footprint of EV batteries. We recommend that EV battery LCAs include both the cradle-to-gate and use phases. In particular, the mass-induced energy approach based on the load perspective will be useful for battery life cycle design finding a balance between battery size, cost, and climate impact.

4.01.T-02 Social and Environmental Impacts of the Lithium-Ion Battery End of Life

Julius Ott, University of Graz; Martina Zimek, University of Graz; Rupert Baumgartner, University of Graz; , ; , ; , ; , ; , ; , ; , ; , .

The environmental and social factors of end of life (EoL) processes of lithium-ion batteries (LIB) are still relatively unexplored and largely unknown, especially in the context of the social perspective. Therefore, an environmental and social sustainability assessment is needed to map the processes and evaluate the social and environmental impacts of EoL processes of LIBs.

The main methods for this environmental and social sustainability assessment environmental and social life cycle assessments (ELCA and SLCA). The inventory analysis and impact assessment for these assessments are created through value chain mapping, stakeholder consultation (workshops, interviews, surveys), and literature review. Furthermore, ecoinvent and the social hotspot database (SHDB) are used.

The key social hotspots identified are health and safety as well as transportation related. The attribution of the environmental impacts is still ongoing but potential aspects are global warming potential, toxicity and resource depletion.

The results can be used to treat potential social and environmental “hotspots” with extra care e.g. because of the increased risk of thermal runaway in the dissassembly process, divers precautionary measures can be taken to reduce this risk. Furthermore the results can be benchmarked with conventional battery cell production (with potentially higher social and environmental impact) to propose a shift towards a Circular Economy.

4.01.T-03 Life Cycle Inventory for Structural Battery Cell Production

Natalia Sieti, Chalmers University of Technology; Ruben Tavano, Chalmers University of Technology; Leif Asp, Chalmers University of Technology; Magdalena Svanström, Chalmers University of Technology.

In this study a novel undocumented laboratory-scale structural battery cell production is presented. To date, production processes for structural batteries are under development and offer limited availability of data. Conducting LCA on structural batteries is currently difficult due to the limited published LCI analysis.

Here presented is the approach applied for LCI analysis of a structural battery cell, of lithium-ion type at an early stage, for laboratory scale production at Chalmers University of Technology. Life cycle inventory data were directly measured and collected on site, or were calculated using site-specific activity data and literature available.

With reference to potential development decisions, and as the research on structural batteries still grows, the generated LCI data will be presented. Considering the significance or current lack of LCI data, LCI results will be presented as part of a prospective LCA study following participatory up-scaling.

It is noted that this study neglect the use and End of Life management of structural batteries and/or the use of recycled material. Continued developments are expected to address advances for laboratory scale data from cradle to gate and may result in different or additional outcomes.

Lastly, it is pointed out that the generated life cycle inventory and analysis of this lithium-ion structural battery cell can be shared with conventional LCA and prospective research in applications across the transport sector.

4.01.T-04 Bio-Based Materials for Lithium-Ion Batteries

Rebecca Thorne, Institute of Transport Economics; Linda Ager-Wick Ellingsen, Institute of Transport Economics.

Lithium-ion batteries (LIB) currently represent the state-of-the-art technology for energy storage, but they convey multiple sustainability issues relating to high production environmental footprint and use of critical and strategic materials. Large amounts of research is thus dedicated to next generation energy-dense batteries using more sustainable, non-critical materials. To this end, the goal of this work was to evaluate environmental impacts (per 1 g material from cradle-to-gate) relating to production of a fully bio-based anode and compatible quasi-solid-state electrolyte where the key inputs to both materials involved biological silica and mesoporous silicon, which was produced and derived from barley husks. A process-based and attributional approach was taken for the life cycle assessment (LCA) work with use of primary lab-scale production data for the foreground system, with the goal to provide early-stage optimization insights for material developers.

Results show that the lab-scale production of bio-based Si had a high carbon footprint of 15.2 kg CO2-eq/g, and acidification, toxicity and crustal scarcity potential impacts of 0.08 mol H+-eq/g, 6.01E-8 CTUh/g and 2608.0 kg Si-eq/g, respectively. Impacts were high for other materials also – with (as example) GWP values of 21.7 kg and 10.4 kg per g for the bio-electrolyte and Si/CNF aerogel anode, respectively. Electricity input (European mix) dominated the contribution towards impacts for all materials, although even when a Norwegian electricity mix was used with high contribution from renewable sources, impacts were still high due to the waste intensive nature of the processes. These results demonstrate the resource and electricity demanding nature of lab-scale production processes.

Overall, while one may expect that bio-based material production is environmentally friendly as barley husks are a waste that "comes for free", production of bio-silica and bio-silicon, as well as downstream materials, have high associated impacts. This means that if bio-Si is to be environmentally competitive with conventionally produced Si, and the bio-anode and electrolyte materials to be competitive for LIB production, industrial production must be significantly more energy and resource efficient. As such, industrial production methods should already be considered now to map out future scaled-up production processes and foresee environmental hotspots.

4.01.T-05 Transparent and Informed Decision-Making Through a Holistic LCA Approach In Battery Energy Storage Systems

Luka Smajila, KTH - Royal Institute of Technology; Ketan Vaidya, Northvolt; Farzin Golzar, KTH - Royal Institute of Technology.

Battery Energy Storage Systems (BESS) face scrutiny for their environmental footprint, posing challenges for transparent decision-making due to limited data and impact declarations. While extensive focus is given to mobile batteries used in electric vehicles, phones, scooters, and other mobile applications, stationary systems are often not thoroughly assessed in their use-phase. End-of-Life (EoL) consideration can further complicate the environmental impact assessment, as different EoL strategies can lead to system expansion and cross-boundary impact declaration. This study aims to develop a comprehensive and holistic approach to assessing the direct and indirect environmental impacts of BESS throughout their entire life cycle. By incorporating prospective elements for production and recycling, dynamic assessment of the use-phase, and optimization for system size and operation, this research seeks to uncover the intricate relationship between environmental burdens and specific technologies, services, installation locations, and end-of-life strategies.

A key focus of this study is the integration of multiple methodological approaches across the BESS life cycle. Inclusion of prospective LCA (pLCA) and dynamic LCA (dLCA) elements in different stages of the BESS life-cycle, future technological, market, and policy conditions can be captured.

By leveraging in-house developed BESS-specific optimisation models, a thorough understanding of environmental impacts in the use-phase, that are specific to the BESS application and location. Furthermore, an exploration of different EoL pathways produces a holistic understanding of the consequences and implications of different design, development and implementation choices across the BESS life-cycle. This is developed by assessing different BESS technologies and chemistry, namely Lithium-ion, with addition of Sodium-ion and Nickel-Cadmium batteries.

Thus, this research aims to provide insights tailored to the specific needs of various stakeholders in the BESS value chain.

The results of this study will offer a comprehensive assessment of BESS environmental performance, highlighting the trade-offs and synergies between different technologies, operational strategies, and end-of-life scenarios. This holistic approach will contribute to informed decision-making, facilitate transparent sustainability assessments, and ultimately promote the development and deployment of more sustainable BESS solutions for the energy transition.

4.01.P - Life Cycle Assessment of Batteries

4.01.P-Tu052 Life Cycle Assessment of Lithium Recovery Alternatives from Mine Tailings

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Lithium (Li) is a key material for achieving Europe's Green Deal plan, mainly due to its importance for electric mobility which is highly dependent on the production and market penetration of electric vehicles that rely on lithium-ion batteries. However, the extraction and processing of primary lithium has led to several environmental implications for the local communities and ecosystems.

This study presents a life cycle assessment comparison of processes for the recovery of Li from waste streams, specifically mine tailings from a former mining site of pegmatite, which was considered to have interesting concentrations of Li in its composition. This study was conducted at laboratory level to support decision making from an early stage of development for meaningful influence in Li recovery process design.

A comparison between several potential processes was conducted to determine the environmentally best alternative. Several pre-treatments and leaching processes were considered for separating Li from the solid sample into a liquid solution for further processing. Primary data was collected with the support of a digital data platform. The inventory of each scenario was completed through the use of established life cycle databases to match material and energy flows, and compile background data for Belgium and European conditions. The main hotspots were identified for the developed pre-treatments and leaching processes, considering the functional unit of 1 g of leached Li.

The results showcased that the main drivers of the environmental impacts were the energy consumption (Belgium energy mix) and the incineration of the waste generated during leaching. The production of electricity driven from natural gas and the share of imported energy from the Netherlands (with significant shares of energy generated from coal and gas) dominated the analysed categories, followed by incinerating the waste generated during leaching, i.e., the remaining solid sample after the leaching process. The leaching with acids and bases had the highest impacts and the alternative with the lowest impacts was water leaching of the pre-treated sample with roasting. A sensitivity analysis was conducted for normalized initial Li concentrations (highest and lowest), which showed that process performance is the main factor when selecting the best Li recovery alternative. The obtained results were provided for decision making, supporting the further development of this technology.

4.01.P-Tu053 Is a Stationary Second-Use the Most Sustainable Option for a Lithium-Ion Battery of a Car?
Martina Serra, Swiss Federal Laboratories for Materials Science and Technology (EMPA); Roland Hischier, Empa-Swiss Federal Laboratories for Materials Science and Technology.

As the demand for lithium-ion batteries (LIBs) grows in both the electric vehicle and stationary energy stor-age sector, extending their lifespan becomes increasingly important to reduce the consumption of valuable materials used in their production.

This study delves into the comparative evaluation of the sustainability implications of two options: continued use of the batteries in vehicle applications to maximize their life-time, and repurposing them for secondary uses in energy storage applications. In the first strategy, batteries nearing the end of their initial life cycle within vehicles are assessed to determine their state-of-health (SoH). Those with sufficient capacity (higher than 80%) are subsequently reintegrated into vehicle use, extending their operational lifespan. Conversely, batteries failing to meet specific performance thresholds, typically below 80% of capacity, are repurposed for other sector than the automotive sector, such as for energy storage in a second-use application.

Through a comprehensive life cycle assessment (LCA), we evaluate the environmental footprint of each op-tion, focusing on nickel-manganese-cobalt (NMC) battery chemistry and considering the entire life cycle of LIBs. All stages including manufacturing, use phase, treatment and end-of-life, are investigated. A basket of product approach is used in the study in order to ensure a proper comparison of the two investigated op-tions, accounting for LIBs' use within vehicles and their secondary application for energy storage for the same amount of time. Additionally, factors such as battery degradation and energy efficiency fade are con-sidered, using sensitivity analysis to evaluate the influence of key parameters.

The potential environmental impacts of the two alternatives are evaluated across all 16 impact categories included in the Environmental Footprint (EF 3.0) impact assessment method. With this evaluation, the main critical stages and their drivers are identified in order to determine the most suitable option from an environ-mental perspective.

4.01.P-Tu054 Does "Abundant Materials" Equal "Environmentally Benign"? Life-Cycle Impacts of Sodium-Ion Batteries
Sanna Wickerts, Chalmers University of Technology; Rickard Arvidsson, Chalmers University of Technology; Anders Nordelöf, Chalmers University of Technology/Institute of Transport Economics; Patrik Johansson, Chalmers University of Technology/ALISTORE – European Research Institute; Magdalena Svanström, Chalmers University of Technology.

The world is ramping up its production capacity for batteries due to their potential to enable a fossil-free energy and transport system. There are several types of battery technologies, both those already existing on the market, e.g., the dominant lithium-ion batteries (LIBs), and so-called next generation batteries (NGBs) that are not yet produced at large scale. For both, it is important to assess the life cycle environmental and resource impacts, as potential burden-shifting can then be identified and addressed. In addition, if battery developers and producers obtain this kind of information before design is locked and manufacturing processes established, making changes is less demanding and costly. The sodium-ion battery (SIB) is one NGB that has promising life cycle environmental and resource performance compared to LIBs, as this NGB is possible to produce with geochemically abundant materials only. While we have previously conducted a cradle-to-gate prospective life cycle assessment (LCA) of the SIB cell production, with cathode active material production based on primary manufacturer data and upscaled production, there is a clear need to extend this system boundary to encompass all phases of the SIB life cycle.

We have now conducted a prospective LCA encompassing the whole life cycle of the SIB, i.e., from raw material extraction to end-of-life. Compared to the previous study, the SIB cell production modelling has been updated to represent large-scale production more accurately. In addition, several end-of-life options have been explored, as large uncertainty currently exists regarding this for SIBs. Lastly, decarbonized background scenarios have been considered to understand the environmental potential of SIBs in a fossil-free society. The results reveal the life cycle impacts from cradle to grave, indicating, for example, a reduced environmental burden in production compared to previously published results. Furthermore, the overall results indicate that the SIB obtains lower environmental impacts than the LIB, implying that abundant materials equal environmentally benign(er) in this case.

4.01.P-Tu055 LCA of an Energy Community with Electricity Storage: Vanadium Redox Flow Battery vs. Li-Ion Battery
Eva-Maria Wiener, University of Applied Sciences Burgenland; Gerhard Piringer, University of Applied Sciences Burgenland.

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.

4.01.P-Tu056 Prospective Life Cycle Assessment of Hydrometallurgical Recycling of Lithium-ion Battery Cells in a Large-scale Industrial Facility

Mudit Chordia, Chalmers University of Technology; Anders Nordelöf, Chalmers University of Technology/Institute of Transport Economics; Rickard Arvidsson, Chalmers University of Technology.

Lithium-ion batteries (LIB) are the most common choice of energy storage technology for battery electric vehicle (EV) applications today. Specifically, the nickel-manganese-cobalt (NMC) chemistry is favored due to its properties such as high energy density, high voltage, low self-discharge rate, long cycle life, and high charging and discharging rate capability. Several key constituents used in the NMC chemistry, such as cobalt and lithium, are already listed by the European Commission in their critical raw materials list, while nickel is listed as a strategic material with demand expected to rise for EVs in the coming years. Additionally, extraction and production of these raw materials are energy- and chemical-intensive processes that often leads to local, regional, and global pollution. Thus, to address the environmental aspects of raw material extraction and supply constraints, battery manufacturers are actively working with secondary material suppliers (battery recyclers) to address the growing demand for raw materials in their LIBs for the coming years.

This study will develop scenarios for the future hydrometallurgical recycling of LIBs to assess its potential recycling to reduce the environmental pollution impacts of LIBs. Data in terms of energy, and chemical use for recycling will be sourced from a leading large-scale battery recycler in Sweden. The recycling facility will apply hydrometallurgical processes to recover the cobalt, lithium, nickel, and other materials from NMC batteries. The study will implement a prospective life cycle assessment model to evaluate the environmental and resource implications of using recycled materials in LIBs. A sub-goal of the study will be to assess whether the supply of secondary materials in the future meet the demand of the raw materials in the batteries. The results are expected reveal the potential of large-scale hydrometallurgical recycling for reducing impacts of NMC LIBs.

4.01.P-Tu057 Prospective Life Cycle Assessment of Organic Redox Flow Batteries

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Organic redox flow batteries are emerging as a promising stationary energy storage solutions due to their versatility in meeting power and energy requirements across various application scales, as well as their long lifespan, low self-discharge, heightened safety, and the avoidance of expensive minerals. Evaluating the environmental performance of technologies during their early development stages is crucial for identifying potential environmental impacts and guiding technology development. This study assessed the environmental performance of two emerging TEMPO-based redox flow batteries: an all-organic flow battery (OFB) and a hybrid flow battery (HFB), using life cycle assessment (LCA). The environmental impacts of the two batteries are benchmarked to the conventional vanadium flow battery (VFB). Two functional unit were considered: 1 kWh theoretical storage capacity and 1 kWh electricity delivered over the battery lifetime. This study constructed a battery deisgn model based on industrial data and design equations, calculating the required amount of battery materials. Additionally, a battery performance model was built to estimate the amount of electrolyte requried and the energy delivered over the battery's lifetime. Moreover, a global sensitivity analysis (GSA) was performaned to discover the relative contribution of input parameters to the total uncertinty. Overall, the results showed that OFB and HFB outperformed VFB in most impact categories, except for freshwater ecotoxicity and resource depoletion. Regaring the relative contribution of battery components, the energy subsystem are the biggest contributor to the total impacts regardless of the battery type, functional unit, and the environmental impact categories. This is associated to the high environmental emissions of the electrolyte. GSA highlighted that electrolyte capacity fade is the parameter affecting the results most , emphasizing the need for battery researchers to prioritize improvements in this performance parameter for the development of sustainable flow batteries.

4.01.P-Tu058 Energy-Efficiency and Environmental Performance of Lithium-ion Batteries as an Energy Carrier for Container Ships

Meem Muhtasim Mahdi, University of Iceland; Shahabuddin Ahmed, Technical University of Munich.

The maritime shipping industry is frequently criticized for its adverse environmental impacts on the marine ecosystem and global atmospheric conditions, which resulted in growing stakeholder concern for adopting greener energy systems to facilitate sectoral decarbonization and achieving the IMO's 'net zero' target. In this context, ship electrification can become a promising solution since most cleaner fuels require sophisticated storage facilities. Therefore, this research evaluates how energy-efficient and eco-friendly will the usage of lithium-ion batteries (LiBs) be as a potential energy carrier for a medium-sized container ship sailing across the Subarctic region by a case study method. The case ship's technical specification and operational information were collected from the manufacturer's spec sheet and annual port reports to develop the case scenarios and voyaging interfaces for three different LiBs and heavy fuel oil (HFO). The battery propulsion systems' operational adequacy and energy efficiency were tested by MATPOWER (v. 8.0) software and compared with HFO consumption. Besides, a bottom-up integrated system approach was employed to analyze the environmental performance of each case scenario by life cycle assessment (LCA). The life cycle inventory model for each case scenario was developed by SimaPro software (v. 9.2) using Ecoinvent (v. 3.8) inventory database based on global marine traffic data. Detailed analysis of the ´well-to-wake´ footprint was estimated by ReCiPe 2016 midpoint (H) methods. Based on the analyses, LiBs would become an emerging energy carrier for container ships to reduce embodied energy consumption and associated emissions from vessel operations compared to conventional marine power systems, and the lithium iron phosphate (LFP) battery showed superior energy conversion potential and environmental performance compared to other LiBs. However, the material extraction and battery disposal process showed an upward trend, contributing to the total ecological footprint. Hence, adopting near-infrared and layer-drying methods for LiBs cell production will be a promising approach to reducing net energy consumption and material loss during battery production. Conversely, including electricity grids connected to renewable energy sources in the energy mix option and integrative charging stations in the ports will become fruitful initiatives for upscaling LiBs usage for marine vessels to foster sustainable maritime operations.

4.01.P-Tu059 Up-to-date LCA of a Sodium-Ion Battery Based on Primary Data

Friedrich Jasper, Karlsruhe Institute of Technology; Manuel Baumann, Karlsruhe Institute of Technology; Marcel Weil, Karlsruhe Institute of Technology.

The growing need for energy storage capacity prompts an exploration of alternatives to Lithium-Ion batteries (LIBs), which mostly rely on critical raw materials, like Co, Ni, Li and natural graphite. Sodium-Ion batteries (SIBs) are being considered as their biggest competitor, known for their potential as a more environmentally sustainable, safer, and cost-effective alternative. Therefore, a Life Cycle Assessment (LCA) of an SIB based on primary data is conducted. The analysis incorporates a comprehensive material and energy flow assessment, forming the basis for the Life Cycle Inventory and therefore the LCA of the cell. To conduct this assessment, the OpenLCA software and the ecoinvent database are employed, offering a robust framework for evaluating the environmental impact of the SIB pouch cell from cradle to gate.
Former research showed that the cradle-to-gate impacts of SIBs are comparable to those of LIBs in absolute terms, as the production processes are very similar. However, the SIB is expected to have a higher environmental impact per kWh storage capacity in most impact categories due to its lower energy density compared to LIBs. In contrast, the use of abundant materials in SIBs is expected to result in a lower impact in certain impact categories such as resource depletion. Currently, the number of studies evaluating the environmental footprint of SIBs are limited, highlighting the need for up-to-date assessments given the transformative nature of the technology. A study based on primary data results in a robust analysis and advances data availability in the literature, building a basis for upscaling and other comparative LCAs in the future. This comprehensive LCA helps in understanding current impacts and identifying areas for improvement in the production and supply chain of SIBs, making it essential for stakeholders and policymakers.

4.01.P-Tu060 Future Climate Imapcts of All-Solid-State Batteries

Shan Zhang, Swedish University of Agricultural Sciences; Daniel Brandell, Uppsala University; Mario Valvo, Uppsala University; Bernhard Steubing, Leiden University; Per-Anders Hansson, Swedish University of Agricultural Sciences; Åke Nordberg, Swedish University of Agricultural Sciences.

Despite significant advancements, lithium-ion batteries (LIBs) have reached their limits in specific energy and energy density, hindering full electrification of the vehicle sector. To address this challenge, all-solid-state batteries (ASSBs) are considered promising next-generation solutions. This study aims to evaluate the climate impacts of two ASSB chemistries using a prospective life cycle assessment (pLCA) for the years 2025, 2030, 2040, and 2050, under two battery designs and two climate target scenarios.

A battery dimensioning model was developed to calculate the required materials and corresponding specific energy for two designs of ASSBs. The study modeled all batteries with identical dimensions to ensure a fair comparison. The pLCA approach focused on climate impacts during the production phase, using the attributional cutoff method and the integrated assessment model (IAM) REMIND to explore future scenarios.

The findings reveal that ASSBs exhibit higher climate impacts than conventional LIBs, primarily due to the environmental burdens associated with solid-state electrolytes. However, from 2025 to 2050, climate impacts are expected to decrease for all battery types. Optimizing battery design, particularly by reducing the weight of non-cathode layers, can significantly mitigate the climate impacts of ASSBs.

4.01.P-Tu061 Challenges in Conducting Carbon Footprint Declarations in Compliance with the European Union Battery Regulation

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The European Union (EU) Battery Regulation mandates carbon footprint declarations for all electric vehicle (EV) batteries placed on the European market from 2025. These declarations are implemented through a delegated act, which specifies the calculation methodology via guidelines and requirements. While the delegated act aims to provide detailed and specific guidelines, it also introduces complexity for practitioners and reporting companies. An advantage of the delegated act is that is enables comparability between carbon footprint of batteries. The methodology includes the raw material acquisition, production, distribution, and end-of-life phases, thereby striving to promote circular economy principles. Despite the significance of the EU Battery Regulation, there has been a limited number of LCA studies that adopt the approach proposed by the Joint Research Centre (JRC). This gap highlights the difficulties practitioners face in aligning their assessments with the mandated guidelines and comparing existing LCA results with carbon footprint declarations. To address this issue, we conducted an LCA of a battery gigafactory following the EU guidelines, providing insights into the practical challenges encountered during regulation compliant carbon footprint calculations. Several specific challenges were identified in terms of the functional unit definition, circular footprint formula implementation, and end-of-life modelling. These challenges are discussed using the estimated LCA results. While the EU Battery Regulation’s guidelines are designed to promote sustainability and end-of-life considerations, they also introduce significant challenges for LCA practitioners. Especially with regards to the implementation of the circular footprint formula, as also highlighted by several industrial actors. Addressing these challenges will be crucial for the successful implementation of carbon footprint declarations in compliance with the EU Battery Regulation. This work underscores the need for ongoing refinement of guidelines and support for practitioners to facilitate the adoption of sustainable practices in the battery industry.

4.01.P-Tu062 Comparative Life Cycle Assessment of Lithium-Ion and Redox-flow Energy storage systems

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Background and Purpose: Lithium-ion batteries and vanadium-redox-flow-batteries represent suitable technologies for battery storage systems (BSS). Recent studies explored the replacement of the vanadium-based electrolyte with vanillin-based electrolytes extracted from lignin. The sustainability of battery technologies for BSS has become a highly relevant topic. However, comparing their environmental impacts through life cycle assessments (LCA) presents a challenge, due to different methodological assumptions made across LCA studies. Thus, a harmonised methodological approach could help address this issue. By following recommendations on conducting comparative LCAs and identifying environmentally relevant battery parameters, this study aims to contribute to the methodological harmonization.

Methods: A cradle-to-grave assessment of two types of LIBs (nickel-manganese-cobalt-oxide and lithium-iron-phosphate) and two types of RFBs (vanadium-based and vanillin-based) will be conducted in order to avoid trade-offs between different life cycle stages. A literature research will be conducted to identify relevant battery parameters.

(Preliminary) results: Considering LIBs, the battery cell manufacturing is identified as an environmental hotspot of the production phase, while the impacts of the VRFB production are highly affected by the electrolyte. The analysis of the vanillin-based electrolyte showed that the energy demand has a significant influence on GWP. Due to the early stage of the study, a number of key parameters has yet to be included within the LCA model, especially with regards to the use phase. Furthermore, end-of-life (EoL) scenarios need to be implemented for each technology.

Conclusions: Comparative environmental assessments of battery technologies are crucial to determine the most suitable technology for specific use cases as well as to benchmark new technologies. The aim of this study is to propose a framework for comparative LCAs of BSS, which can serve as a support for future LCAs.

4.01.P-Tu063 Beyond Battery Life Cycle Assessments: Creating a Framework to Measure Sustainability for the UK Electric Vehicle Battery Supply Chain

Sophie Kempston, University of Warwick.

Background
Electric vehicles are key to decarbonising the road transport sector, and they are expected to grow exponentially in the UK over the coming decade. They are powered mainly by lithium-ion batteries (LIBs), which have been chosen for their long cycle life, high efficiency, and high energy density. However, there are serious sustainability concerns with the manufacture of LIBs, and steps must be taken to ensure that the increase of LIBs is managed as sustainably as possible.

Methods
A systematic review of the sustainability factors for lithium-ion batteries from UK electric vehicles was conducted. This included academic and grey literature, such as guidelines and policy documents. This review was then followed with 25 semi-structured interviews with participants from across the battery industry, including life cycle assessment (LCA) practitioners and those assessing sustainability using other methods. A follow-up survey was then run to assess the importance of these factors and start to prioritise them.

Results
The results show that a variety of factors must be considered when talking about sustainability, many of which are not currently captured in battery LCAs. The literature review identified 44 factors across six categories of sustainability: political, environmental, social, technical, legal, and economic (PESTLE). The interviews expanded on these, and stretched to 80 indicators across these PESTLE dimensions. The factors cover the supply chain from battery design through to end-of-life, and also take into account wider factors and their impact on sustainability, such as policy and regulatory changes. This raises issues for the future of evaluating sustainability in the battery space.

Conclusions
This research shows that there are much wider sustainability requirements for batteries than environmental, and that traditional categories in an LCA may not go far enough to assess true sustainability. Future work will seek to address how we can integrate these wider categories into an LCA framework, how to prioritise indicators effectively, and how to identify and resolve trade-offs.

4.01.P-Tu064 A Battery Is Only as Green as the Sum of Its Parts – A Case Study on Future Impacts of Nickel Production for Cathode Active Material Manufacturing

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Considering a gigafactory which operates on renewable energy, remaining CO2 emissions from lithium-ion battery manufacturing mainly come from upstream mining and mineral processing. As an illustration, for a nickel-cobalt-manganese (NMC)-811 cathode active material factory, nickel class I production accounts for ~ 36% of the overall CO2 emissions. Therefore, the prospective life cycle assessment (PLCA) of an NMC-811 gigafactory should depict technological evolution within nickel's supply chain. Nevertheless, no PLCAs currently include technology-switch when modelling the future impacts of nickel production. The present work reconstructs prospective life cycle inventories for nickel via disaggregation of emerging processing routes.

An algorithm was developed utilizing the open-source olca-ipc python library to deconstruct the direct contributions of upstream processes. The algorithm is applied to the product system for nickel class I from smelting and refining of nickel 16% concentrate from sulphide ores in ecoinvent v.3.9.1. Smelting of nickel concentrate (73%) and diesel consumption during mining operations (10%) were identified as crucial to remodel due to the relative importance of their direct contribution to specific climate change impacts. This hypothesis is challenged via our remodelling. Process models are created for alternatives to smelting. Calculated from engineering design correlations and available primary data, inventories remain flexible to multiple process configurations. Furthermore, a fraction f of wind electricity is applied to fulfill energy requirements for extraction and comminution, otherwise met by diesel. Energy consumption is further parametrized as a function of ore grade and ore particle size.

Specific climate impacts per kg nickel are reduced by 6% when conservatively setting f to 0.7 and ore decline to 50% for a specific mine. Furthermore, preliminary results for the tank bioleaching route forecast additional CO2 reductions of 45 % per kg Ni, assuming hydro-powered operations. Consequently, the climate change impact of NMC-811 manufacturing is reduced by 19%. Potential burden shifting risk will be assessed in consistency with the planetary boundaries framework. We envision the application of our prospective modelling technique to a wider set of metals sharing the studied processing routes; with the aim of better quantifying environmental implications of the energy transition.

4.01.P-Tu065 Influence of Technical Performance Parameters on the Life Cycle Impacts of Large Stationary Energy Storage Systems

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The sustainability and safety of stationary energy storage systems (ESS) have recently become an issue because these are considered to play an essential role in renewable energy transitions. For example, Vanadium-based redox-flow batteries (VRFB), vanillin-based organic redox-flow batteries (vanillin-ORFB), and Li-ion batteries (LIB) represent potential ESS options. Because of numerous and high uncertainties currently prevailing, a continuous and comparative evaluation appears highly relevant for well-informed decisions to be made on ESS. In this work, focusing on the operation phase, potential life-cycle impacts are analyzed by setting up a model which includes a range of performance parameters as well as their variations. As a starting point, (1) technical performance parameters of energy storage systems (VRFB, LIB, vanillin-ORFB) are collected and their estimated ranges summarized; (2) cradle-to-use emissions (global warming potential) of a battery system with a defined functional unit are calculated based on proposed use-phase related equations that include a set of performance parameters; and, (3) variations in emissions resulting from potential ranges in the use-phase performance of the influencing parameters are tested with a sensitivity analysis. The preliminary results indicate that VRFB perform better than LIB (cradle-to-use) due to the high cycle life assumed. The estimated use-phase related emissions are strongly influenced by the technical parameter assumptions and are currently pointing towards a better use-phase performance of LIB compared to VRFB due to higher round-trip efficiency. Building on this work, the proposed equation will be continuously improved and adapted; different stationary ESS cases will be included for comparative assessment; and further sensitivity analyses will be performed (including Monte-Carlo simulation). Linking potential improvements in the performance of respective technical parameters with the related life-cycle impacts can be helpful in setting priorities in ESS technology development and thus support environmentally conscious decision-making. Accordingly, levers for improvement will be identified and recommended. To allow fair comparisons between different ESS, it necessitates a standardized procedure on how to perform comparative LCAs and guidance on assessing how performance parameters influence the life cycle emissions.

4.01.P-Tu066 Environmental Profiles of Key Materials for All-Solid-State Lithium-ion Batteries – Early Insights from the AM4BAT Project

David Wilde, Leitat Technological Center; Marta Escamilla, Leitat Technological Center.

In response to the increasing demand for safer higher energy and power density Li-ion batteries at reduced cost, the EU-funded AM4BAT project aims to develop an anode-free all-solid-state battery (ASSB), manufactured using novel 3D-printing technology, for electric vehicle applications. To also promote an optimal sustainability performance and ecodesign, the project is accompanied by a multilayer Life Cycle Sustainability Assessment to aid in the material and manufacturing process selection.

This presentation focuses on the environmental impact screening results from investigating key solid-state battery materials (LLZO and NMC811) and processing alternatives (e.g. solid-state vs wet precipitation). A cradle-to-gate environmental LCA methodology was applied, building on processes available on the Ecoinvent database and foreground data gathered from project partners, to determine impact hotspots and the relative performance of material and process alternatives using the Environmental Footprint impact assessment method.

The investigation found that LLZOs produced via solid-state method perform considerably better than those produced via co-precipitation, due to higher process outputs relative to inputs and lower energy consumption. LLZO produced via electrospinning was found to have the highest impact even when accounting for disproportional energy consumption at lab-scale. On the material level, the lanthanum-containing input material was identified as responsible for the largest overall share of impacts in all cases, and it was found that paying attention to doping solutions applied can also contribute to environmental impact reductions by avoiding higher impact materials, such as tantalum. Similar findings were obtained for the NMC811, where the reported material produced via solid-state method at industrial scale also displayed the lowest impacts in most key impact categories, such as climate change and resource use, even relative to the existing Ecoinvent database solution. The nickel-based inputs were found to be responsible for the largest overall impact share, although cobalt materials also contribute significantly in all processing scenarios.

The findings of this study are an important contribution to inform the material and manufacturing process selection towards novel ASSB solutions from an environmental sustainability and ecodesign perspective, ensuring that GEN4 batteries fulfil their promise beyond technical and safety performance aspects.

4.02 - Ex-ante, Prospective, and Circular LCA for Buildings: Envisioning Future Impacts

4.02.T-01 Renovate or Replace - What is the Optimal Decision for a Single-Family House Considering Cumulative CO2 Emissions?

Roland Hischier, Swiss Federal Laboratories for Materials Science and Technology (EMPA); Cristina Dominguez, Swiss Federal Laboratories for Materials Science and Technology (Empa); Efstathios Kakkos, Swiss Federal Laboratories for Materials Science and Technology (Empa); Dietmar Gross, E.ON Group Innovation GmbH; Georgios Mavromatidis, Swiss Federal Laboratories for Materials Science and Technology (Empa); Kristina Orehounig, TU Wien.

With the goal to reduce emissions of the building sector the question arises what is the best strategy for the existing building stock to reduce the overall impact of buildings on CO2 emissions. Is it better to renovate a building, or to rebuild it in a very energy efficient manner? In the on-hand study a framework was developed to assess cumulative CO2 emissions throughout the lifecycle of a single-family house. The here developed framework is based on a building energy simulation tool to assess operative emissions together with a life cycle assessment framework to study environmental impacts and benefits associated with the materials and systems used during the construction or renovation process of the building. As a case study a typical German single-family house was considered together with a variety of different scenarios of reno-vation and/or replacement. The aim of this analysis is to evaluate the trade-off between costs, emissions and energy consumption of the buildings during a time span of 25 years.

The approach consists of an analysis of relevant data sources, modelling of the geometry and construc-tions which is then used by both the building simulation and the life cycle assessment tool. A rigorous scenario analysis has been performed to evaluate life cycle costs, emissions and energy consumption for both retrofitting and replacement buildings.

Results for the examined single-family house show that the lowest CO2 emissions during the lifetime of the analyzed building can be achieved with a sustainable replacement building (-2.05 kgCO2/m2/year) by using a heat pump with ground collector coupled with PV under the condition of reusing the materials as much as possible, so that carbon remains stored in the wooden materials. Interestingly, the application of small renovation measures, such as replacing the windows, doors and replacing the natural gas-based heating system by an electricity-based is on the edge for achieving the 2°C CO2 emissions target at much lower costs.

4.02.T-02 Reuse and Recycling Potential for Mass Timber Curtain Walls: A Consequential, Ex-Ante Life Cycle Assessment
Marley Dowling, University of Waterloo; Matt Roberts, University of California; Costa Kapsis, University of Waterloo; Chris Bachmann, University of Waterloo.

The built environment significantly impacts global carbon emissions and resource use, necessitating advanced life cycle assessments (LCAs) that can adapt to evolving technologies and conditions. Mass timber curtain walls offer notable environmental benefits while having a shorter lifespan compared to entire buildings, making them particularly suited for advanced end-of-life studies. This research employs consequential LCA to evaluate the long-term viability of reuse and recycling strategies for the primary curtain wall components such as aluminium, insulation, and glass. By integrating emerging (ex-ante) technologies with varying technological readiness levels and accounting for projected grid decarbonization, our study compares these advanced strategies against current business-as-usual end-of-life practices.

A detailed life cycle inventory of the mass timber curtain wall was developed using manufacturer specifications. The analysis included life cycle stages: production (A1-A3), transport (A4), construction (A5), end-of-life processes (C1-C4) and Module D. Scenarios were modelled using a static grid and anticipated grid carbon intensity. Additionally, benefits and loads beyond the system boundary were considered, modelling potential additional material or component lifespans as separate processes, and calculating the avoided emissions where applicable.

Our findings reveal that while current reuse and recycling methods outperform landfilling in terms of environmental benefits, emerging recycling techniques show potential for even greater reductions in global warming potential. However, these advanced methods face scalability challenges due to their present laboratory or pilot-scale operations. The results indicate that grid decarbonization scenarios could increase overall global warming potential, driven by Ontario's reliance on natural gas as a marginal fuel source, which highlights the importance of considering energy source transitions in future assessments.

This study underscores the importance of continued research and development in recycling technologies to optimize the life cycle impacts of mass timber curtain walls.

4.02.T-03 A Participatory Approach to Prospective Life Cycle Assessment of the European Cement and Concrete Sector
Anna M. Walker, European Commission - Joint Research Centre (JRC); Paola Federica Albizzati, Joint Research Centre - European Commission; Pelayo García-Gutiérrez, Joint Research Centre - European Commission; Leonidas Milios, Joint Research Centre - European Commission; Davide Tonini, Joint Research Centre - European Commission.

The European Green Deal aims for net-zero emissions by 2050, necessitating a shift towards a Circular Economy (CE). Despite the CE's central role, existing policies have not achieved desired outcomes, prompting the need for a recalibrated policy framework. The RecalibrateCE project seeks to enhance EU CE policy by assessing the sustainability impacts of policies in carbon-intensive sectors, with a focus on the cement and concrete sector, a significant source of CO2 emissions. The project uses a mixed-methods approach, combining prospective life cycle assessment (LCA) with scenario analysis derived from the four normative European Strategic Foresight scenarios. We compare a business-as-usual LCA model with configurations incorporating CE policies and potential regulatory, economic, and technological interventions, referred to as CE levers. Then, for the sensitivity analysis of the LCA, a participatory approach enabled the quantification of the four socio-economic scenario narratives. First, an expert workshop determined the effectiveness of the CE levers within the four socio-economic scenarios. In a second step, this was complemented with a sense-making session composed of a smaller set of experts to identify background values that mimic the scenario conditions. Preliminary findings show that CE levers related to material reduction work best under strong government intervention, whereas reuse levers are most effective with high sustainability awareness. Recovery levers also best succeed with supportive state legislation. The adapted effectiveness coefficients of the CE levers, categorized into low, medium, and high ranges, will be employed to represent the scenario characteristics directly affecting the CE levers in the sensitivity analysis. Moreover, the sense-making session suggested to adapt two main external factors: to scale general demand for materials and to vary trade patterns in line with the scenario narratives. Using a participatory approach, the project merges foresight and LCA to offer a new perspective on prospective LCA, considering the uncertainty of future narratives. The findings will inform policymakers on cement and concrete flows and their environmental impacts that go beyond climate change considerations, in the context of a future-oriented CE policy framework.

4.02.T-04 Prospective Life Cycle assessment of Building Stocks: What Does it Take to Reach Net-Zero in 2050?
Nicolas Alaux, Graz University of Technology; Dominik Maierhofer, Graz University of Technology; Carlos E. Caballero-Güereca, Graz University of Technology; Alexander Passer, Graz University of Technology.

Background and Purpose
Greenhouse gas (GHG) emissions must be radically reduced in all sectors to achieve climate neutrality by 2050. Buildings have a key role to play, as they are responsible for 36% of global GHG emissions. The aim of this study is to determine the extent to which GHG emissions from Austrian buildings can be reduced in 2050 and what carbon removal measures are required to achieve net zero.

Methods

Two future scenarios are applied to a building stock model that projects the GHG emissions of buildings in Austria from 2023 to 2050. The first, “With existing policies”, is a reference that takes current policy measures into account. The second, “Net zero trajectory”, includes additional GHG emission reduction strategies targeting material production and selection, recycling, energy efficiency and supply or lifestyle changes. Prospective life cycle assessment (LCA) is used to forecast both operational GHG emissions and embodied GHG emissions (from materials production, transport, construction, replacement, renovation, demolition and waste processing) up to 2050. Carbon removal technologies are then discussed to address the remaining GHG emissions.

Results
The results show that to achieve net-zero GHG emissions in 2050, it is crucial to prioritise reducing operational GHG emissions, which can be achieved through high renovation rates and investment in renewable energy generation. With a number of ambitious material-related measures and additional lifestyle changes, i.e. a slight reduction in the vacancy rate of dwellings, GHG emissions from new buildings can reach net zero in 2050. The remaining GHG emissions are around 3 MtCO2eq in 2050. Given the number of office, retail and apartment buildings assumed to be built between 2023 and 2050 and the carbon removal potential from the carbonation of cement-based materials, achieving net zero GHG emissions in 2050 would mean that almost half of these buildings are equipped with additional direct air capture (DAC) technologies, based on current literature data.

Conclusions
The life cycle GHG emissions of the Austrian building stock have the potential to be reduced by 92% by 2050. To compensate for the remaining emissions, around half of the newly constructed buildings would have to be equipped with DAC. This raises the question of feasibility given how much electricity is needed for DAC. Carbon removal solutions outside the building sector may need to be explored.

4.02.T-05 Comparative Assessment of Decarbonization Strategies in New Urban High-rise Residential Buildings in cold climatic regions of China based on Consequential Life Cycle Assessment
Kaiwen Li, Cardiff University; Vicki Stevenson, Cardiff University; Eleni Ampatzi, Cardiff University.

The Chinese government has initiated high-level national policies to facilitate the zero-carbon transition, subsequently prompting sub-departments and local governments to develop complementary policies in buildings tailored to local conditions. However, the lack of evidence regards the long-term effectiveness and cross-sectoral implications of building decarbonization strategies offered by policies, hinders comprehensive assessment and prioritisation. Tailoring CLCA (Consequential Life Cycle Assessment) specific to China’s context will enable a comparative assessment of the performance of technical decarbonisation strategies under future scenarios. This research focuses on communities of new urban high-rise residential buildings and defines the representative case study according to the newest policies and norms. Decarbonization Strategies extracted from the abovementioned policies are used to establish potential future building scenarios. This research enables us to compare the whole-life carbon reduction potentials of various strategies applied to China’s new high-rise urban residential buildings within a chosen temporal window (up to 2060). The result will expose the carbon reduction potential of selected decarbonization strategies in new buildings in 5-year time periods between 2025 and 2060, where the influence of the decarbonization process of the energy sector and industry on those strategies is considered. This will provide evidence for the most effective carbon reduction strategies to be addressed in future policy in the appropriate timeframes to further reduce lifetime carbon emissions in new high-rise residential communities in urban China. Visualisation of the result over a series of 5-year periods could help inform policymakers on appropriate actions to significantly reduce carbon emissions of new urban residential buildings in the long term. The expected contribution of this research is to support the compilation of long-term zero-carbon transition policies in residential buildings in China for responding to international commitments to tackle climate change.

4.02.P - Ex-ante, Prospective, and Circular LCA for Buildings: Envisioning Future Impacts

4.02.P-We047 Integrating Dynamic Prospective LCA and Circularity Strategies for Sustainable Buildings
Haitham Abu-Ghaida, Hasselt University; Anna Wöhler, Chalmers University of Technology; Alexander Hollberg, Chalmers University of Technology; Michiel Ritzen, The Flemish Institute for Technological Research (VITO); Sebastien Lizin, Hasselt University.

Purpose: This study aims to advance the application of Life Cycle Assessment (LCA) for buildings by transitioning from a static framework to a Dynamic Prospective LCA that incorporates future environmental databases. This research aims to evaluate how integrating varying socio-economic pathways (SSPs) and climate targets into LCA can influence the assessment of a building’s environmental impacts, particularly in circularity strategies. The study seeks to understand the extent to which circularity strategies remain viable and beneficial when viewed through a dynamic and temporally sensitive LCA approach.

Method: The study employs a methodology that combines the established Ecoinvent database with the prospective modeling capabilities of the PREMISE tool. To develop the dynamic aspect, activities occurring in specific years are mapped to the prospective database of that year. This approach integrates SSPs to forecast the environmental impacts of buildings over an extended period. The methodology involved creating a baseline LCA using current data and developing a series of projected LCAs at five-year intervals, each aligned with different SSPs and climate targets. These projections accounted for anticipated changes in material technology, energy consumption patterns, and the efficiency of recycling processes. A case study building was modeled to provide a real-life application of the dynamic LCA approach.

Results: The results indicate that the dynamic prospective LCA methodology offers a more nuanced and forward-looking perspective on the environmental impacts of buildings. By mapping activities to the prospective data of specific years and incorporating SSPs and climate targets, the method allows for evaluating how future changes in socio-economic conditions and climate policies might affect the sustainability of building materials and technologies. This approach highlights the potential of dynamic LCA to inform more adaptive and resilient circularity strategies.

Conclusion: The dynamic prospective LCA methodology enhances the robustness of environmental impact assessments by incorporating future socio-economic and technological changes. This approach underscores the importance of dynamic modeling in developing and evaluating circularity strategies for sustainable buildings. The study concludes that adopting a forward-looking LCA framework can significantly influence circularity strategies’ perceived viability and benefits, guiding more informed decision-making for sustainable building practices.

4.02.P-We048 Renovate or Replace, Phase II: Finding Optimal Solution for Multi-Family Houses Considering Cumulative CO2 Emissions

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Renovation and replacement measures are crucial to reduce operational emissions of the existing building stock. Although replacement of an old building may lead to significant energy savings, the embodied emissions of the new construction may outweigh these benefits, making solution to the “renovate or replace” dilemma less straightforward. The problem gets more complex due to uncertainties in modelling future scenarios. The first phase of this project demonstrated that replacement is the preferred option for a single-family house. The current second phase aims to identify the optimal solution for a broader range of multi-family houses (MFH) considering cumulative CO2 emissions, energy consumption and total costs.

The study focuses on five MFHs located in Essen, Germany and examines three renovation and two replacement scenarios over a 25-year time frame. The replacement options include mineral and sustainable design alternatives. The embodied and operational emissions of the selected scenarios are quantified using the Life Cycle Assessment (LCA) method and ökobaudat background database. The functional units are “1m2 of conditioned area per year of the analysis period” for renovation measures, and “person per year” for the replacement scenarios. The foreground data on electricity and heating demands are simulated with DesignBuilder by dividing the analysis period into smaller sub-periods and using respective weather files to reflect the changes in future energy demand. The corresponding electricity and district heating mixes are modelled according to the projected energy transition targets. The sensitivity analysis will focus on the influence of modelling choices, future reuse of building components, and biogenic carbon.

The building selection and the energy simulations have been completed and the LCA analysis is underway. The hypothesis is that renovation solutions for MFHs could offer greater benefits compared to replacement options. Project completion is scheduled for June 2024, and its findings are expected to play a crucial role in advancing sustainable practices, particularly in the management of MFHs in Essen, therefore fostering a more sustainable built environment.

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4.02.P-We049 Circularity – Not So Straightforward: The Application of Lca for the Performance Assessment of Renovations in a Circular Economy Context

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Today, buildings are responsible for roughly 40% of EU’s energy consumption. The renovation of homes is crucial for the enhancement of energy performance of buildings, reducing this demand. The Circular Economy (CE) can support this transition, however performance assessment in this context lacks consensus. Life cycle assessment (LCA) offers a plausible solution but has traditionally been developed for linear systems and against the backdrop of the built environment (BE), for new construction developments. Application of LCA to a CE context, particularly for renovation projects, therefore, warrants methodological caution.

This paper presents a systematic review following the PRISMA reporting guidelines, exploring the complexities and key considerations of evaluating circularity and environmental performance of renovation projects through LCA. Traditional LCA methods may not fully capture the benefits of circularity, leading to incomplete evaluations. Central to the investigation are questions regarding the treatment of the existing building, allocation approaches, the reference study period and biogenic carbon accounting.

The review reveals a lack of consensus on methodological approaches such as whether to include or exclude the existing building in the analysis. These divergent methodological approaches influence the outcome of the assessment, complicating result comparability and decision-making processes in renovation projects. In addition, the paper reviews which indicators can be used in tandem, to provide a more comprehensive view of circularity and support more circular renovation decisions.

These findings highlight the need for transparency and standardization in LCA methodologies pertaining to renovation projects in the CE context to address uncertainties and methodological consequences, ultimately guiding better informed decisions in sustainable and circular renovations. This study contributes to the ongoing debate on improving LCA practices to align with CE principles in the BE.

4.02.P-We050 Prospective LCA of Advanced Insulating Materials for Buildings to Estimate the long-term Environmental Impacts

Angela Daniela La Rosa, NTNU; Ákos Lakatos, University of Debrecen.

Background and Purpose: This study explores advanced insulating materials, highlights research innovations, discusses potential market opportunities, and examines their practical applications in the building sector to promote energy use and CO2 emission reduction and sustainable solutions by using the life cycle assessment (LCA) as guidance. The state of the art in this field provides a good number of comparative LCA[1] for the market leading materials (stone wool, glass wool, polystyrene, polyurethane polyisocyanurate) and the renewable based materials (hemp, cork, nano-cellulose, aerogels). Literature findings highlight a great potential of renewable resources as insulation materials for the building sector, nevertheless the need of using additives to guarantee the raw materials durations and fire resistance, generates a consistent contribution to the environmental impact.[1] Therefore, the development of more environmentally friendly renewable based-insulating materials is an important area of research

Methods: Experimental analyses were conducted to determine thermal conductivity, density, and specific heat capacity of selected samples. Comparative LCA was conducted for the selected functional unit (FU) defined as the mass (in kg) of insulation materials needed to provide the same thermal resistance R (or its reciprocal the heat transfer coefficient U) over a set area, most often 1 m2. FU=$R*\lambda*\rho*A$, where R is the thermal resistance ($m2*KW$), λ the thermal conductivity of the material, ρ the density of the material, and A the area. Market prices of different materials were used to conduct the life cycle cost (LCC) analysis associated to the same functional unit and system boundaries of the LCA.

Results and Conclusions: The research findings will contribute to foster a comprehensive understanding of the future of insulating materials for sustainable buildings and to estimate the long-term environmental impacts of current building designs and practices.

[1] S Füchsl, F Rheude, H Röder. Life cycle assessment (LCA) of thermal insulation materials: A critical review Cleaner Materials Volume 5, September 2022, 100119.

4.02.P-We051 Understanding Embodied Greenhouse Gas Emissions from Real Case Building Renovation projects in Sweden: Quantification, Drivers and Characterization

Zoé Barjot, KTH; Tove Malmqvist, KTH Royal Institute of Technology .

In recent years, the climate impacts of new constructions have been widely recognized, researched, and subject of mitigation strategies. However, in Sweden more than half of the building stock's greenhouse gas emissions (GHGe) are linked to maintenance, renovation, and rebuilding of the existing stock. Related to the European Union "renovation wave", life cycle-based research on renovation has mainly focused on understanding and addressing the trade-offs between operational and embodied energy and GHGe in building projects. However, the knowledge of what drives embodied GHGe in renovation projects, and how current renovation practices affect embodied GHGe remains largely unresearched.
This study analyses the nature of current renovation projects in Sweden and their associated embodied GHGe and resource consumption, to identify hotspots and which parameters these hotspots depend on. Specific attention is given to the case of fit-outs and explore the potential of sufficiency strategies. Data from 30 renovation projects in Sweden were collected from public and private developers in the form of bill-of-materials and complementary project specific parameters. Qualitative data was collected by consulting public and private actor representatives to complete the datasets. The data was processed using Swedish generic environmental data and categorized to calculate embodied GHGe according to EN15978 at both the renovation project scale and the renovation measure scale. The latter to improve comparability of the results since renovation projects are of high diversity.
This method provides a deeper understanding of the levels and variations of embodied GHGe associated with different renovation measures. Further analysis focuses on identifying the drivers for GHGe from fit-outs as well as the most influencing parameters (e.g. former use of the building or floor layout).
The outcomes of this study are a first step towards the development of benchmarks and novel metrics to better understand how renovation measures affect resource consumption and embodied GHGe over time. This approach can challenge the current norms and mitigation strategies in the renovation of buildings and provides useful knowledge when renovation projects are the object of climate-related regulations.

4.02.P-We052 Selective Deconstruction: A Case Study of Waste Management Optimization

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Buildings contribute significantly to environmental impacts, necessitating a focus on optimising their life cycle assessments (LCAs). However, the current studies focused mainly on evaluating and optimising environmental impacts related to embodied emissions and operational energy. Therefore, this paper utilises the LCA methodology to assess potential burdens and benefits associated with the selective deconstruction of the administrative building case and the management of material flows. Three scenarios are compared: optimistic, representing the highest possible recovery rate of material; pessimistic, representing landfilling of materials; and real-practice conditions assessing the waste management based on inventory from the case study of selective deconstruction. The analysis identifies critical hotspots in the conventional waste management processes for construction and demolition waste, offering insights into potential areas for improvement. The highest potential for improvement is related to processing and quality management of concrete waste. Furthermore, thanks to the selective deconstruction approach, steel scrap recycling contributes to the beneficial impact of the deconstruction case study. This comparative study aims to enhance the sustainability of building practices by addressing critical waste management issues and promoting more efficient use of resources throughout the building end-of-life stage.

4.02.P-We053 Advancing Environmental Performance in Construction Industry Through Systemic and Holistic Thinking Using LCA

Magnus Sparrevik, NTNU.

The construction industry and built environment represent a significant pressure on the environment by being the largest consumer of natural resources in the world. To effectively reduce the environmental impact during the building life cycle there is a need for environmental life cycle assessment tools at different systemic levels.

At product level use of environmental product declarations (EPD) can provide transparent information on the environmental impact from the construction materials, products and services. The use of EPDs is transparent and allows the builder to make well-informed environmental decisions in the procurement process. However, use of EPDs alone may bias the decisions towards the construction phase and therefore not give enough focus on impacts created in the use or end of life stages of the building.

Life cycle assessment at the building level is a far more extensive system analysis. This increases the possibility to reach an optimal building design adapted for a wider life cycle context. Even though building analysis seems comprehensive, it is still a case-to-case driven method. This makes standardisation difficult and may give more costly and less reproduceable solutions since improvements are tailored to each building individually.

To further standardise environmental performance at the organisational level, building certification schemes based on life cycle principles may be used. This will give higher built environmental standards and better organisational performance. Even though building certification may be effective at the organisational level it is still voluntary and can be used differently within each organisation, reducing the systemic impacts.

Methods at system level are therefore needed. A broad variety of policy, standards, and regulations exists for the built environment. The EU taxonomy is a valid example of a regulation based on life cycle methodology with expected broad scale systemic effects. This will direct the construction sector towards less resource use in all life cycle stages when enforced by national regulation.

Development and structure between the levels are not coordinated or governed unidirectionally, but rather occur simultaneously at different levels. Methods at lower systemic levels may improve production processes and stimulate the market to create circular and innovative building solutions, whereas methods at higher systemic levels can used by real estate builders, trade organisations and governments to create incentives for development and innovation in a broader perspective.

4.02.P-We054 Prospective Life Cycle Assessment of Building Structures

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1. Background and purpose

Building structures represent a large part of the embodied carbon of a building due to the use of carbon intensive materials such as concrete or steel. With this and the implementation of legislations aiming at reducing Greenhouse Gases (GHG) emissions of the building sector in mind, construction companies are encouraged to invest in alternative construction systems or to use less carbon intensive materials. To keep up with this demand, material producers are gradually changing their means of production. For instance, cement producers substitute clinker with fly ash or kiln or integrate carbon capture and storage technologies, transforming the production systems and related supply chains.
Prospective Life Cycle Assessment (PLCA) has been conducted at the material scale for cement and concrete, describing a possible evolution of material environmental impacts. This study aims to bring this PLCA results to the scale of a building structure. It addresses the evolution of the impacts on climate change of structures and assesses whether alternative construction systems are needed to significantly reduce related GHG emissions, or evolution of construction material production technologies of typical building structure is sufficient.

2. Methods

To that end, prospective scenarios of typical building structures materials are defined. For concrete, the scenario considers alternative cement with clinker substitutes and carbon capture and storage technologies. For steel production, a shift from using blast furnace to electric arc furnace and hydrogen technology is considered. Electrification of wood exploitation machines is considered. Those scenarios are used to establish the foreground LCA processes for timber, concrete or steel structures. Using IMAGE integrated assessment model and premise python library, background databases for transport and electricity mixes are generated and integrated to the structure models.

3. Results

Prospective impact of typical building structures in 2050 are evaluated and compared to 2023 typical structures and to potential alternatives considering 3.5° and 1.5° degree scenarios. Results show a diminution of impact concerning carbon emissions. However, technological changes lead to impact transfer on certain categories.

4. Conclusions

This study provides an insight on the environmental impact of structures and the potential decarbonization pathways and their consequences.

4.03 - Combined Methods for Energy Futures in Life Cycle Assessment

4.03.T-01 Life Cycle Assessment of Energy Transition Scenarios

Romain Sacchi, Paul Scherrer Institut; Alvaro Hahn Menacho, Paul Scherrer Institut; Christian Bauer, Paul Scherrer Institut; Evangelos Panos, Paul Scherrer Institut; Peter Burgherr, Paul Scherrer Institut.

Background and Purpose: The ongoing transformation of the energy sector necessitates robust methodologies for assessing the environmental impacts of evolving energy systems. This study introduces pathways, a Python package designed to perform Life Cycle Assessment (LCA) on energy transition scenarios. By characterizing them through the lens of LCA, the objective is two-fold: 1) broaden the spectrum of indicators against which energy transition scenarios are benchmarked, and 2) go beyond the mere reporting of direct emissions by attributing supply chain emissions to final energy consumers.

Methods: pathways characterizes integrated assessment models (IAM) and energy system models (ESM) scenarios through the lens of LCA. It uses a time-adjusted LCA database for each time step of the scenario to calculate the impacts of an activity, sector, or entire energy system. Unlike the traditional emissions reporting by IAM and ESM, pathways considers the supply chain relationships between producers and consumers, offering a detailed view of direct and indirect impacts, further broken down by life-cycle stages and geographical origin of impacts. The tool also deals with double-accounting of emissions and offers a practical approach to sensitivity and uncertainty analyses. Lastly, it allows for quantifying the resource use implied by energy transition scenarios in terms of land, water, and metals, for which quantification has been neglected so far.

Results: Using the case of a net-zero scenario for Switzerland, pathways shows that: 1) while territorial greenhouse emissions reach zero within Switzerland by 2050, substantial emissions persist abroad, 2) significant trade-offs exist, with a marked increase in land and metals use, as well as increased toxicity impacts associated with extractive activities, 3) an overall trend where domestic impacts are progressively externalized to other world regions.

Conclusions: This study demonstrates the effectiveness of the pathways package in characterizing energy transition scenarios with LCA. The findings provide valuable insights into the complexities of energy supply modeling, including the geographical distribution of impacts. By providing a larger spectrum of indicators to assess future energy systems, pathways contributes to better-informed discussions around energy transition.

4.03.T-02 Dynamic and Prospective LCA Combined with Energy System Modelling to Address the Temporal Impact of Energy Production and Storage

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1. Introduction

Transitioning towards renewable energy sources is essential for achieving sustainability targets. It is important to assess which type of technologies are most favourable. In this study a combined dynamic and prospective LCA is combined with energy system modelling to assess the potential benefits of electricity production from wind energy.

2. Materials and methods

The research conducts a full cradle-to-grave LCA encompassing all stages of the wind turbine life cycle. The functional unit is defined as 1 kWh of electricity delivered by the wind turbine, and its impact on global warming has been assessed. The LCI data has been gathered from various secondary sources, and inputs for the wind turbines have been scaled towards a power capacity of 3 MW.

In the next step PATHS 2050 - Scenarios towards a carbon-neutral Belgium by 2050 from the TIMES-Be model are being used to produce bi-hourly resoluted databases of future energy system changes with timex_lca. Next, we assess the benefits of producing wind energy depending on the timing of its production

3. Results and Discussion

The preliminary results from the LCA show that among the three types of wind turbines, the direct drive electrically excited synchronous generator wind turbine type has the largest impact on global warming. The direct drive permanent magnet synchronous generator wind turbine and the gearbox double fed induction generator wind turbine roughly have the same impact on global warming.

Most emissions occur at the production phase of the wind turbine. Impacts at the use phase and end of life are limited. Current practices are used when modelling the end of life. Converting the static LCA towards a dynamic prospective LCA and combining with the outcomes of an energy system model is still work in progress.

4. Conclusions

This presentation has the main goal of showing how, by combining a fully dynamic and prospective LCA with the results of ESM, it is possible to develop a more realistic scenario to evaluate the impact of renewable electricity production from various wind turbine technologies in Belgium. The results in more realistic LCA models which could better inform stakeholders in making informed decisions concerning the sustainability of renewables.

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4.03.T-03 Green Hydrogen Production in Uruguay: Integrating Life Cycle Assessment and Energy System Optimisation using Impuls-urbs Framework

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Green hydrogen is crucial for decarbonizing energy systems, particularly in sectors where electrification is challenging. Latin American countries have significant potential for green hydrogen production, with Uruguay's "Green Hydrogen Roadmap" aiming to export up to 1 million tons annually by 2040, requiring about 18 GW of additional renewable capacity.

To address growing energy demands and formulate climate policies, sophisticated tools like energy system models (ESMs) are essential. However, existing ESMs often neglect indirect emissions, providing limited insights. Life cycle assessment (LCA) techniques provide a holistic view by including these emissions but are typically applied post-optimization. This study integrates LCA insights directly into Uruguay's energy system optimization using a novel framework called Impuls-urbs. The primary aim is to show how policymaking is influenced when considering the production of key materials and supply-chain greenhouse gas emissions within the optimization.

The optimization results from a typical ESM and Impuls-urbs are compared for the case of Uruguay's electricity and hydrogen sector. They showed a significant need for future expansion within Uruguay's electricity sector, driven by hydrogen production demands. Integrating upstream processes in the Impuls-urbs model revealed shifts in the optimal energy mix. Representing the indirect emissions and additional energy needs for the key material production influenced the power plant expansion priorities.

In conclusion, Impuls-urbs offers a comprehensive assessment of Uruguay's green hydrogen ambitions, guiding strategic decision-making and policy formulation towards a sustainable energy transition. This approach provides insights into economic, environmental, and technical challenges and opportunities by evaluating the interconnected development of the material sector, electricity system, and hydrogen sector.

4.03.T-04 Prospective Life Cycle Assessment of Hydrogen Production via Electrolysis: The Role of Background and Foreground Electricity

Juliana Steinbach, Mines Paris -PSL; Joanna Schlesinger, Mines Paris -PSL; Paula Pérez-López, Mines Paris -PSL; Romain Sacchi, Mines Paris -PSL; Thomas Beaussier, Mines Paris -PSL.

By 2050, hydrogen production via electrolysis will use electricity from both the grid and dedicated renewables like photovoltaic (PV) systems. Excess renewable electricity can be fed to the grid, with renewable energy certificates (REC) purchased during low production periods. This dual coupling poses modeling challenges due to the differing environmental impacts of grid electricity and PV credits. Additionally, modeling imports in future electricity mixes complicates assessments. This study examines how methodological choices in electricity consumption affect the prospective Life Cycle Assessment (pLCA) results for hydrogen produced in France in 2050.

Methods
The study models foreground and background activities to assess the production of 1kg of hydrogen via Proton Exchange Membrane electrolysis at 30 bar. It focuses on modeling foreground electricity from PV and the background electricity mix from the French market, supplied through the grid.

The prospective PV inventory uses data from the IEA Photovoltaic Power Systems Programme (IEA PVPS) and efficiency improvements for 2050 from Premise. Hydrogen production configurations range from PV systems designed to operate within the electrolyzer's 1MW capacity to scenarios where 100% of hydrogen production is powered by PV credits.

The French electricity market is modeled using RTE's 'Energy Pathways to 2050' (FE2050). These scenarios include imports varying from 3.5% to 5.6%. Two modeling approaches address imports: using Integrated Assessment Model (IAM) scenarios for a Western Europe market group and adapting the current share of electricity from neighboring countries to future scenarios.

Results and Discussions

Preliminary results show that greenhouse gas (GHG) emissions from hydrogen production via electrolysis vary significantly based on electricity consumption modeling. Using PV credits for hydrogen production results in approximately 1 kgCO2-eq, while relying solely on grid electricity results in around 4 kgCO2-eq. Different configurations yield various impacts, reflecting a mix of PV and grid electricity.

Conclusions
Integrating PV systems into hydrogen production is crucial for reducing GHG emissions. The GHG impact varies based on the electricity source and import modeling choice. Accurate allocation of PV impacts is essential to avoid double-counting and accurately represent the environmental benefits of renewable energy.

4.03.T-05 Consequential Life Cycle Assessment of Wind-to-X Using Near-Future Wind Energy Models

Lasse Poulsen, Aalborg University; Søren Løkke, Aalborg University.

Power-to-X (PtX) is projected to be a major driver for the EU strategy for an integrated energy system. Therefore, there is a need for comprehensive life cycle modelling of PtX and its role in the future energy system. This further implies, that it is insufficient to base the modelling on historical energy data, as the energy system is facing a major shift, which PtX itself will affect.

We have mapped the state of the art of PtX LCAs, and propose a consequential and prospective approach, applied to a Danish case plant, using results from the energy system modelling software EnergyPLAN to model energy inputs in the LCI. Furthermore, we have created updated wind turbine models in cooperation with Vestas, as wind power will be a major energy source for PtX, and it was therefore deemed necessary to have updated and prospective data to reflect wind energy production. By creating prospective databases using the Premise software, we have accounted for the future end-of-life of the turbines.

The results of the LCA highlight the importance of how the energy system is modelled, as this dominates life cycle impacts. We propose integrating energy system modelling to achieve valid inputs for how the energy system will react to PtX integration and thus support policy-decisions regarding the future energy system. It is found insufficient to model PtX using 100% wind or solar, as the energy output from these varies with weather patterns, and thus there will be a need for a varied set of energy sources to uphold production. Methodological choices regarding energy production can drastically change the LCA results, and this should therefore be accounted for in a consistent and valid manner to reduce/remove the influence of bias in those choices.

4.03.P - Combined Methods for Energy Futures in Life Cycle Assessment

4.03.P-We055 General Lci Model for Heat Supply and Demand With Specified Temporal and Spatial Data: Determining Marginal Heat Suppliers for Informed Decision Support

Timen Boeve, Aalborg University; Lasse Krogh Poulsen, Aalborg University; Søren Løkke, Aalborg University; Iva Ridjan Skov, Aalborg University.

The Danish government has made a commitment to reduce Danish GHG emissions by 70% in 2030 compared to the emissions in 1990, this has led to an increased need to make decisions that efficiently reduce GHG. Therefore, this paper proposes a generalised framework to establish localised marginal technologies mixes for different district heating grinds in Denmark based on consequential life cycle assessment. Two different marginal technology mixes are proposed, a current capacity marginal heating grid, based on the marginal supply of the current installed capacity. Secondly capacity changes marginals are proposed, which reflect changes in the current capacity either by introducing new capacity such as electric heat pumps or the removal of current capacity e.g. by the closure of a coal power plant. Data from the Danish Energy Agency and Weidema's heuristic 4-step model are utilized to establish the marginal suppliers. The spatial dimension is important to consider for heating as, heating cannot be transported over long distances, meaning the model needs be on a local heat-grid-scale. Significant technology variations are observed between different grinds further emphasizing the need for a generalised framework that can assess a wide range of grids and technologies. Furthermore, the timing of the emissions has been accounted. The framework will furthermore include modelling heating outside the established DH grid. This submodule will overlayer user-defined detached heat technology with scenario based DH-grid extension. Most of these detached heating technologies are expected to be electric heating pumps or biomass-based heating, where a consistent modelling approach to constraints on material inputs and feedstocks are important. The main result is a spreadsheet-based interactive model where the user input place and time-horizon for heat-related decisions to be made.

4.03.P-We058 A Life Cycle Assessment of Green Hydrogen Production Using Proton-Exchange Membrane Water Electrolysis Coupled with Desalination in Saudi Arabia

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Green hydrogen, considered a crucial element in the transition towards a sustainable energy future, offers the potential to mitigate greenhouse gas (GHG) emissions and reduce reliance on fossil fuels. This study explores the viability of hydrogen production through proton exchange membrane water electrolysis (PEMWE) as a key driver of decarbonization within the Vision 2030 framework in the Kingdom of Saudi Arabia. A first-of-a-kind life cycle assessment of green hydrogen production using PEMWE in the kingdom is performed. The inclusion of water desalination processes adds an important dimension to the assessment, reflecting the local context and resource availability. Two main scenarios are assessed; one is powered by solar energy through photovoltaics (PV), and the other is powered by wind energy through onshore turbines. The global warming potential (GWP) results present a strong reduction of GHG emissions of up to 95% compared to the state-of-the-art steam methane reforming process if only the electrolysis process is powered exclusively on electricity generated by renewable sources, such as solar and wind energy. The scenarios powered by solar and wind energy show a GWP of 3.62 and 0.84 kg CO2 eq / kg H2, respectively. The metal depletion (MD) is assessed to consider the implementation of rare materials, with a 0.072 kg Cu eq / kg H2 for the former case and 0.039 kg Cu eq / kg H2 for the latter. A contribution analysis reveals that the emissions primarily stem from the electricity source, thereby minimizing the impact of both the electrolyser itself and the water desalination process. The findings underscore the importance of renewable energy integration and process optimization in minimizing environmental impacts and advancing the sustainability of green hydrogen production. Overall, this research contributes to advancing scientific knowledge and informs policymakers and stakeholders about the environmental implications of adopting green hydrogen technologies in Saudi Arabia and beyond.

4.03.P-We059 Assessing the Validity of the Net-Zero Claims of Electricity Generation From "Waste Coal"

Marie-Odile Fortier, University of Nevada, Las Vegas; Alyssa Pfadt-Trilling, University of California; Amir Sharafi, University of Nevada; Sierra Lema, University of Nevada.

In recent years, a few US companies using "waste coal" for electricity generation generation have been promoting this as a sustainable approach. They tend to use higher efficiency power plant designs, such as pressurized fluidized bed combustion, and some project the addition of carbon capture and storage units. Additionally, they claim avoided emissions from collecting "waste coal," either as a waste product of coal processing or as remaining coal in mines that are no longer operational, that risks ignition and uncontrolled burning otherwise. The large amount of ash that is generated is considered a beneficial coproduct and its management is excluded from consideration. However, their assessments of how power generation from "waste coal" could be net-zero in its greenhouse gas (GHG) emissions contain both unsupported assumptions and inaccuracies. We present a life cycle assessment that addresses these issues and recalculates the life cycle GHG emissions of electricity from "waste coal." A cradle-to-grave approach was covered and assumptions of cobenefits were explored in sensitivity and scenario analyses. The heat content of "waste coal" was updated to a more representative value in our LCA model, and moisture effects were taken into account. The results of this study indicate that "waste coal" has a higher carbon footprint than traditional coal for electricity generation under current technological conditions.

4.03.P-We060 Consequential Life Cycle Assessment Of On-road Electric Mobility Deployment In France

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The EU proposes challenging GHG emissions reduction targets of 80% - 95% by 2050, relative to 1990 emission level. In France, the transport sector, mainly on-road, dominates the country's GHG emissions representing 31% of emissions in 2019. In this respect, public policies on electric mobility play a decisive role in decarbonising transport and meeting the targets.

While electric vehicles present many opportunities, such as reducing GHG emissions and improving air quality, especially in urban areas, and decreasing the energy dependence on fossil fuels, their massive deployment raises some questions. Transportation electrification is a strong driver of demand for minerals and metals used in batteries and increases constraints on local electricity grids.

In this context, Ademe (The French Agency for Ecological Transition) launched a study to evaluate the environmental and economic consequences of the deployment of electric mobility (vehicles and charging infrastructure) in France towards 2035. The objective is to evaluate the impact of different deployment scenarios (for cars, trucks, buses and coaches) compared to a reference scenario.

The consequential life cycle assessment (C-LCA) was selected as the most appropriate approach for the study. The C-LCA is being conducted using Simapro software and ecoinvent database for background processes. This is a multicriterial approach and the results will be calculated using midpoint EF 3.1 and endpoint Impact World+ indicators. Detailed power system simulations using Artelys Crystal Super Grid are being performed to assess the impact of the electric mobility scenarios in the electricity production, transmission and distribution power systems. The results of these simulations are then used as entry data for the C-LCA.

The introduction of EVs in the French on-road fleet are based on the ADEME Transition 2050 scenarios: 1) «regional cooperation », 2) «reparation bet» and compared to a trend scenario as a reference. These will be associated with several charging behaviour patterns: A)« slow charging » (most of the EVs charged at home, with low charging power; B) « daytime charging » (most of the EVs charged at home, behavioural changes to shift some of the charging periods to solar PV production hours), and C) « fast public charging » (low access to home charging and high need for public charging at higher power).

4.03.P-We061 A Methodological Approach to Prospective Life Cycle Assessment for the Harmonization of the Foreground and Background Systems

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In the modern world, energy is generated or utilized by sectors like the power sector, industry, transport, and households. Going forward, all these sectors, including their technologies, will undergo massive transformations to achieve sustainable pathways. With the prospective life cycle assessment (pLCA), the future environmental impacts of these technologies can be evaluated over their life time, considering the changes in the foreground and background system. For instance, in the pLCA of fuel cells, the background system handles fuel cell material and energy flows like steel and electricity, while the foreground system includes activities linked to fuel cell's production and use. Future scenarios of both foreground and background systems will be decisive in pLCA for the selection of prospective technologies across the sectors.

Most of the pLCA studies in the literature focus on the implementation of future scenarios in the foreground and background systems individually. Very few of them considered both and observed an inconsistency in the technology selection based on the perspective storylines. This occurs due to the lack of both scenario data and its assumptions of the background systems. Thus, there is a research gap in the identification of changes to life cycle and system data in the foreground in line with the background system.

This contribution answers to how to carry out pLCA for a specific technology, considering the methodological approach of harmonizing the foreground with background systems?

The research methodology involves three steps: identifying key elements in a background system to aid with harmonization, designing the foreground system, and integrating the gathered data of background system into Premise (a tool that facilitates the creation of prospective inventory databases).

The proposed methodology will be tested by applying case studies in all the steps. As part of the harmonization with a decarbonized background scenario in a selected use case, technologies in the foreground, such as green hydrogen for fuel production and carbon capture and storage, were selected.

This harmonization approach stresses the importance and inclusion of background systems in a foreground system design. On the other hand, decision-makers find it easier to select the perspective technologies of their choice when both systems are consistent. It will increase the accuracy of measurement of impact factors related to climate change and material resources.

4.03.P-We062 Coupling Environmental Assessment with Integrated Thermal Energy Storage Systems Modelling

Tanima Sharma, KTH Royal Institute of Technology; Rafael Guedez, KTH Royal Institute of Technology; Silvia Trevisan, KTH Royal Institute of Technology; Andrew Martin, KTH Royal Institute of Technology.

With growing concern about sustainability, technological advancement in energy systems is accelerating. While renewable energy systems have been extensively studied from an environmental perspective, decarbonized heating systems have not yet received equivalent attention. Decarbonising industrial heat is crucial for achieving sustainability goals. In this context, electrification of heat through renewable energy, industrial heat recovery, and district heating networks, integrated with energy storage are vital strategies. This study aims to perform Life cycle assessment (LCA) of integrated thermal energy storage (TES) systems like molten salt, underground storage, and novel technologies like Kyoto's HeatCube. LCA is a valuable tool to measure all the direct and indirect environmental impacts of these systems. However, a significant gap exists between energy system design and environmental impact assessment, limiting the integration of LCA results into decision making. Traditional energy system design often prioritizes technical and economic aspects, neglecting environmental considerations. Similarly, conventional LCA methods frequently lack integration with energy system design, resulting in disconnected assessments and custom models without standardization. To address these limitations, this study proposes a unified framework that integrates dynamic energy system models with dynamic LCA methodologies and compares them with a traditional static approach. By coupling LCA with energy system process modelling, the proposed methodology facilitates accurate Life Cycle Inventory (LCI) inclusion, addressing the common issue of primary data shortages by estimating LCI from early energy system design. This study aims to utilize the advancements in data analytics, computational modelling, and interdisciplinary collaboration to overcome challenges in environmental impact assessment integration with energy systems modelling like harmonizing disparate data sources, addressing uncertainties in future energy scenarios, and defining spatiotemporal boundaries. By combining energy system design analysis with dynamic LCA methodologies, this study aids decision-makers in making more informed choices, promoting the transition towards sustainable and resilient energy systems.

4.03.P-We063 Material Criticality for Clean Energy Technologies: a Systematic Literature Review

Justine Mast, Ghent University; Gwenny Thomassen, Ghent University and University of Antwerp; Sue Ellen Taelman, Ghent University; Jan Mertens, ENGIE; Jo Dewulf, Ghent University.

Background and Purpose: Global policy discussions have increasingly focused on transitioning to clean energy economies, highlighting the risk of supply chain disruptions and the importance of metals and minerals, amongst critical raw materials (CRM), for which often no substitutes are available. Solar and wind will dominate energy production in 2050 while batteries and green molecules will be important for energy storage. All these technologies rely on CRMs, which underlines the importance of assessing material criticality for the energy sector.

Methods: This work conducts a comprehensive review of the literature over the last decade to assess which criticality assessment methodologies have been applied to energy systems from a company perspective. The approach includes the analysis of peer-reviewed articles, reviews, and articles in press.

Results: The review highlights significant heterogeneity in the criticality assessment methodologies across different goals, scopes, and systems studied. The first divergence is related to the commonly used dimensions 'Probability to supply disruption' and 'Vulnerability to supply disruption' although geopolitical indicators are often included. The second inconsistency is related to the integration of environmental and social impacts for which only one paper includes social implications. The third difference is related to the use of mitigation strategies such as recycling and substitutability since there is a lack of harmonization because each paper has its own interpretation of what criticality entails.

Conclusions: The findings highlight the variety of criticality assessment methods used for the energy sector and emphasize the need for a standardized approach. Integrating environmental and social impacts, and mitigation strategies into material criticality assessment is not only feasible, but essential for advancing sustainable practices in the energy sector. These findings can be critical for policy makers, researchers, and industry stakeholders in the energy sector who are seeking to balance economic, environmental, and social outcomes in their operations.

4.03.P-We064 Excess Heat Utilization – LCA Modelling the Temporal Differences and Understanding How These Matter

Frederik Luft genannt Plaisier, Aalborg University; Magnus Mikkelsen, Aalborg University; Mathias Gustavsen, Aalborg University; Thomas Elliot, Aalborg University; Henrik Riisgaard, Aalborg University.

Challenges regarding the assessment of environmental impacts of using excess heat in district heating systems are identified. These are the lack of a standardised approach to allocating impacts of excess heat, the need for inclusion of the temporal aspect of heat supply, and an overwhelming focus on CO2-emissions/climate change. These challenges are addressed using an hourly LCA-model, and a method for allocating impacts to excess heat.

The study makes use of three different scenarios. A baseline scenario on an hourly LCA based on heat supply and demand in the district heating system of Aalborg municipality in Denmark, where environmental impacts for the excess heat supplied to the system have been allocated. The frame of investigation is the share of suppliers and their respective contribution to the total impact every hour over the course of one year (2023). A scenario of the baseline scenario is presented in which no environmental impacts are allocated to the use of excess heat, as it is currently practice. Further, a future scenario based on the planned development and changes of the district heating system 2030 is presented. The current analysed impacts and prospected future developments are put into context of a potential carbon lock-in situation.

Besides expected summer/winter changes the results show that based on the variation in the share of supply over time, the production and delivery of heat shapes the overall changing environmental impacts throughout the timeline. These fluctuations show temporarily full dependency on specific suppliers and their connected environmental burdens. Adding the dimension of more impact categories than the usually considered CO2-emission presents a more comprehensive picture of the different types of suppliers and what their contribution entails.

The study shows how the allocation of impacts in relation to excess heat can shape the perception of it and shape decision-making. It further shows how an hourly LCA model can provide insight into the environmental impacts of a system and support decision-making. The study presents a new approach to assessing the environmental impacts of using excess heat in district heating systems, which challenges the current approach seen in both literature and real-life practice. This can be used to re-think the current and future environmental impacts of district heating systems.

4.03.P-We066 Evaluation of the Life Cycle of Bioethanol and Petrol Blends within the UK's Transport Sector

Vittorio Mercusa, University of Warwick; Simoní Da Ros, WMG - The University of Warwick.

Authors: G. Vittorio Mercusa, Dr. Simoní Da Ros

The transition to sustainable road transport methods is crucial in addressing climate change. Biofuels, such as bioethanol sourced from corn and sugarcane, stand as prominent alternatives to petrol, having a more sustainable profile. This study employs a cradle-to-wheel Life Cycle Assessment (LCA) to evaluate the environmental repercussions of bioethanol and petrol blends within the UK's transport sector, under the scope of the Renewable Transport Fuel Obligation (RTFO). The cradle-to-wheel models were developed using the ecoinvent (version 3.8) database in openLCA (version 1.11.0), and the life cycle impact assessment followed the ReCiPe Midpoint (H) methodology. Findings indicate that the greenhouse gas (GHG) emissions savings from bioethanol blends are less pronounced than previously claimed by the UK's Department of Transport, particularly when the commonly used E10 blend is measured against pure petrol. Although sugarcane ethanol results in a smaller global warming potential, the study suggests that deforestation linked to its extensive land use can offset these benefits. In contrast, the greater water consumption associated with corn ethanol amplifies its environmental impact. The findings situate the study within a global effort to find the most effective strategies for reducing transportation's carbon footprint, challenging the efficacy of current biofuel policies. These findings call for a re-evaluation of bioethanol's effectiveness in contributing to the UK's net-zero emissions goal, highlighting the importance of adopting a comprehensive strategy that balances environmental advantages against the sustainability challenges inherent in both biofuel and petrol production.

4.03.P-We067 Dynamic System Strategies for Climate Social Tipping Points

Thomas Elliot, Aalborg University.

This research aims to understand which courses of action should be established to reach a climate social tipping point (STP) as early as possible, to achieve system transformation by embedding the driving forces in new political and social norms.

Climate change is a wicked problem that requires a combination of solutions – from reducing consumption to rolling out new technologies that can realise the green transition. However, this means crossing a climate STP leading to behavioural regime changes that manifest in climate stabilisation. STPs can be triggered by bottom-up approaches like socio-ecological contagion or by top-down interventions like government policies.

System dynamics is used to model how these bottom-up and top-down approaches can lead to STPs providing a deeper understanding of which types of change lead society towards a more sustainable status.

Quantification of climate STPs is complex and requires engagement across a broad spectrum of scientific disciplines like social, physical, and environmental sciences. Participatory interdisciplinary approaches are embedded in the project by way of expert stakeholder workshops using combined mediated mental modelling and Delphi methods.

4.03.P-We068 Life Cycle Assessment of Latent Heat Thermal Energy Storage in Building Heating and Cooling Systems

Haoyang Dong, KTH Royal Institute of Technology; Luka Smajila, KTH Royal Institute of Technology; Saman Nimali Gunasekara, KTH Royal Institute of Technology; Justin Ningwei Chiu, KTH Royal Institute of Technology.

Among thermal energy storage technologies used in building heating and cooling applications, latent heat thermal energy storage (LHTES) utilizing phase change materials (PCMs) offers several advantages, including high energy storage density and stable temperature regulation during phase transitions. These benefits have led to extensive research and application of LHTES systems. However, while much attention has been given to the material thermal properties, heat exchanger design, and operational strategies of these systems, there has been relatively less focus on their environmental impacts throughout their lifecycle. This study aims to address this gap by presenting a life cycle assessment (LCA) of a chosen LHTES system integrated with a ground-source heat pump (GSHPs) for building heating, with a particular emphasis on its operational phase. This LCA evaluates the economic and environmental impacts of various operational methods, providing a comparative analysis to identify the most environmentally-friendly and cost-effective strategies. A case study based on an existing LHTES installation in an office building in Norway is used to gather relevant data for the LCA. The scope of this LCA encompasses the entire lifecycle of the LHTES system, including the installation phase and decommissioning. During the installation phase, the study examines the environmental footprint associated with the production and transportation of materials, as well as the energy consumed during the installation process. For the decommissioning phase, the focus is on the disposal and recycling of materials, considering the potential for reducing waste and recovering valuable resources. The findings of this study are expected to inform business scenarios that prioritize different aspects of environmental impacts and economic benefits. Also, the study methodology is expected to provide insights for performing LCAs of LHTES systems, in general. By weighing the trade-offs between environmental sustainability and economic viability, the study aims to provide actionable insights for stakeholders in the building industry. These insights will help in making informed decisions about the implementation and operation of LHTES systems, balancing the need for energy efficiency with the imperative of minimizing environmental harm. Ultimately, this research is expected to contribute to a more holistic understanding of LHTES systems, extending beyond their immediate technical performance to encompass broader environmental and economic considerations.

4.04 - LCA of Digitalization, ICT and AI

4.04.T-01 Applying LCA on Artificial Intelligence (AI) Systems - Status Quo, Challenges, and Opportunities

Lina Plataniti, Norwegian Institute for Sustainability Research (NORSUS); Kari-Anne Lyng, NORSUS.

The use of AI-based technologies is expanding to all aspects of modern life, from everyday-life applications to politics, defence, healthcare, economy, science, and others. However, AI systems are complex, requiring advanced infrastructure, large quantities of data, and high use of energy, which result to various environmental/sustainability impacts throughout their life cycle. These impacts should be identified, assessed, and quantified through practices similar to other industrial sectors. In this study, through an extensive literature review, we created an overview of the scientific work that has been done in this field, and recorded the so-far studied environmental impacts, as well as the applied methodologies and specifically the use of Life Cycle Assessment (LCA) on AI systems. For the literature review we used three different approaches: key word search in classic search engines (Scopus and Google Scholar), AI-based tools for literature review (Connected Papers), and forward and backward snowballing from a reference publication with applied LCA on AI systems. We identified 634 publications in total. By screening the abstracts and removing duplicates, we ended up to 39 eligible studies and 17 relevant supporting publications for knowledge building. Importantly, the LCA methodology has been used or mentioned in four publications, but only one presented in detail its application on the estimation of environmental impacts of AI systems. The remaining studies use variable methodologies for estimating mainly the climatic impact of AI of specific life cycle stages. The results of this study uncover the lack of common methodological approaches and the limited application of LCA for assessing the environmental impacts of AI systems. What is missing from the big picture is the active contribution of sustainability professionals and LCA practitioners that will provide scientifically sound estimates and analyses through cross-discipline collaborations with AI/software developers and data scientists, but also with other scientists that will contribute to understanding other (direct and indirect) implications and risks imposed by AI. Methodological challenges are also to be addressed for a valid evaluation of the environmental impacts of AI systems throughout their life cycle.

4.04.T-02 Environmental Effects of AI-Enhanced Textile Sorting
Diego Peñaloza, Research Institutes of Sweden RISE; Uniben Tettey, RISE Research Institutes of Sweden.

The fashion industry has widely-known environmental impacts that have been studied for decades. Typically, LCA studies of textile waste management exclude the environmental impact from sorting because it is considered to be negligible, which may lead to underestimating these impacts. The goal of this work is to explore the environmental effects of applying AI tools for enhanced sorting of post-consumer textile waste by applying LCA.

The LCA studied the impacts of AI training, the potential downstream benefits of enhanced reliability and speed of sorting, and an estimation of a break-even point for AI implementation based on error rate reductions. The system boundaries begin after collection, excluding it since it will not be influenced by the implementation of AI. The sorting process includes the operation of the facility where pre-sorting and sorting is carried out including energy, water use and waste generation. Another module of the system is the AI training and operation, with focus on electricity use and production of hardware. The downstream effects of enhanced sorting are studied in a separate module where three streams are modelled for the fate of the textile waste following the sorting; re-use in Sweden, exports and “special request”, assumed to be only for recycling. For the downstream module, different scenarios were assessed for different levels of reliability of the AI tool applied. The environmental footprint method (EF 3.1) was applied for impact assessment.

The results show that the potential benefits from improved reliability in sorting can very easily offset the additional environmental impacts from developing an AI tool and implementing an AI sorting station in all impact categories. It only takes an 1% increase in reliability to overcome the impacts caused by the training and operation of the AI tool. The results also show that besides the potential benefits of increased reliability, the implementation of an AI tool can also lead to environmental benefits while delivering a more time-efficient function. These results is highly dependent on the assumptions for the fate of the textile waste. Still, given the low rate of recycling and reuse achieved currently in Europe, the potential benefits from any improvement are significantly high.

4.04.T-03 Life Cycle Assessment of Internet Use: Framework, Methodological Challenges and Practical Lessons
Robert Istrate, Leiden University; Victor Tulus , ETH Zurich; Robert N. Grass, ETH Zurich; Laurent Vanbever, ETH Zurich; Wendelin J. Stark, ETH Zurich; Gonzalo Guillén-Gosálbez, ETH Zurich; Guillén-Gosálbez.

Background and Purpose: The environmental footprint of the information and communication technology (ICT) sector is gaining increased public attention, often motivated by concerns around energy consumption. Previous studies have assessed the environmental impacts of the global ICT sector and its components, like data centres, transmission networks, end-user devices, and specific digital services like social media or virtual conferences. Despite these efforts, the application of life cycle assessment (LCA) to address the impacts associated with Internet use from a user perspective (i.e., a consumption-based perspective) remains largely overlooked.

Methods: In this presentation, we introduce a bottom-up framework for quantifying the life cycle impacts of digital content consumption, taking into account user consumption patterns and the necessary Internet infrastructure. Drawing on our previous experience applying this framework to the global average Internet user, we will critically discuss the main methodological challenges and practical lessons, and propose potential pathways forward.

Results: During the goal and scope phase, we will address challenges including: defining user consumption patterns, establishing the functional unit, setting a reference year for technology data, and determining the system boundaries. For the inventory analysis phase, we will explore multifunctionality issues related to the use of end-user devices as well challenges during the modelling of key LCI aspects, including shared digital content, electricity intensity of Internet components, electricity supply to data centres and data transmission networks globally distributed, accounting for impacts embodied in electronic devices, and implications of dynamic inventory modelling.

Conclusions: This presentation aims to foster a broader discussion spanning between the LCA community and ICT experts, contributing to a more harmonized and consolidated LCA methodology for the ICT sector.

4.04.T-04 Carbon Emission Factors for Electronics Production Using a Supply Chain Approach
Nina Lövehagen, Ericsson AB; Jens Malmodin, Ericsson AB.

Emission factors for key electronic components, like semiconductors, displays and Printed Circuit Boards (PCBs) are essential to estimate the embodied greenhouse gas (GHG) emissions of ICT equipment more accurately. The so-called supply chain approach has been used to collect data of ICT equipment from a supplier perspective. The research questions to be investigated are: What are the challenges for investigating the ICT sector from a supply chain approach? How can global electronics production data be used to establish average emission factors (EFs) for specific electronics?

Many companies publish data on electricity use and GHG emissions annually. All ICT equipment can be built up by considering raw materials, mechanics, electromechanics, and electronics divided into components. Company data of electronics production were collected from semiconductor and display manufacturers, EMS (electronic manufacturing services), PCB companies and vendors. The collected data resulted in both global average emission factors, and GHG emissions for electronics production to which data for raw materials, mechanics and electromechanics were added before allocated to industry segments and products.

The GHG emissions of global electronics production related to ICT have been estimated using measured / reported data from about 60 companies covering about 36% of total estimated carbon footprint. The main challenges when establishing the global average EFs are related to gathering data, understanding the data, and handling of double accounting risks. Some key challenges:
- Handling upstream supply chain data gaps and risk for double accounting
- Allocation of data to various types of components/products
- Quantification of the total product output to be able to create a robust average EF

Quantifying the total product output can be difficult even when the total GHG emission estimate is robust, e.g. for semiconductors the total produced wafer area input to all wafer fabs is available, but the total output of functional die area is not fully known. The resulting average EFs (e.g. IC: 2.6 kg CO2e/cm2, PCB: 3 kg CO2e/dm2, display: 2.2 kg CO2e/dm2) can be used by any electronic vendor to calculate a global average benchmark for their designs/products. Specific supplier EFs can replace the average EFs to calculate results more accurate for a specific product. In the future, industry organizations should collect company data and publish global annual updates of their industry.

4.04.T-05 Investigating Contradictory Results for the Future Direct Climate Impact of the Global Information and Communication Technology Sector
Anna Furberg, KTH Royal Institute of Technology; Göran Finnveden, KTH Royal Institute of Technology.

Digital technologies are changing core economic sectors and can promote sustainability but are also causing environmental and social impacts. A few studies have applied life cycle assessment (LCA) methodology to assess the direct climate impact of the global information and communication technology (ICT) sector in the future. However, these studies typically arrive at contradictory results, ranging from decreased to increased climate impacts, which remain to be explained. The aim of this study is to identify reasons behind contradictory future projection results in studies on the global ICT sector's direct climate impact. Studies were selected to be included in the investigation based on recent literature reviews providing general overviews of studies on the global ICT sector's direct climate impact. In total, four studies, considering all three ICT subdomains of end-user devices, networks and data centres, were scrutinized with regard to calculation approaches and strategies for future scenario construction. The results from this study show that model uncertainties are the main reasons behind contradictory results, but parameter uncertainties, e.g. related to values applied for the carbon intensity of global electricity generation, are also important. Comparable parts in terms of scope over the reviewed studies; use phase emissions of computers, smartphones and tablets as well as use phase emissions of networks and data centers, are responsible for a larger share of the respective studies total scenario results at about 50-70%. Incomparable parts, e.g. due to differences in scope or varying level of data aggregation preventing a comparison of some parts with shared scope, are due to model uncertainties and in the order of several hundreds of Mt CO2eq. None of the studies included stocks and flows as well as all life cycle phases of the ICT sector and its subdomains. Furthermore, some of the reviewed studies used strategies for future scenario construction, such as for the use phase of data centres, that in practice do not allow the emissions to decrease. LCA practitioners are recommended to carefully consider the critical aspects identified in this study in future LCAs of ICT and there is a need to develop practical guidelines on how to conduct such studies.

4.04.P - LCA of Digitalization, ICT and AI

4.04.P-Mo042 Digitalisation in the Health Service Sector – The Case of Home Monitoring using IoT and LCA
Birgit Brunklaus, RISE Research Institute of Sweden; Yoon Lin Chiew, Research Institute of Sweden RISE; Anna Axelin, University of Turku; Susanna Likitalo, University of Turku; Petra Sommarlund, Cuviva, E-Health Care; Julia Jockusch, Insel Hospital.

Digitalisation is expected to transform the way we produce and provide services. Digitalisation encapsulates a wide range of systems including e.g. IoT systems with the choice of sensory equipment, algorithms and AI, data storage and integrations into ecosystems of health data. While the sector is developing smarter and digital solutions, less is known about the operation of such systems and the area of Product Service Systems (PSS). The research project includes practical operations of digital solution in the hospital service sector and includes the evaluation of environmental and the social benefits of home monitoring solutions. The research method is based on an LCA approach. The system includes IoT, AI and health service. The functional unit is multi-functional and include digital service and the service provided for patients. We used a modular approach and use several functional units to overcome the methodological challenges. By that we can relate results to different part of the digital service, or the health service provided. The preliminary results show that home monitoring will increase the use of digital equipment and data storage, while reducing transport of patient to and from the hospital. This has highlighted implications on both the product design (direct effects) and the service design (indirect effects). In hospital routine situations, the time is saved to a large extend, and IoT used for providing better service, while patients transport, and climate impacts are reduced. In an emergency, home monitoring might prevent the hospital transports and climate impacts reduced to a larger extend.

4.04.P-Mo043 Life Cycle Inventory of Information and Communications Technology Equipment Applied in Precision Agriculture
Federico Busio, Luxembourg Institute of Science and Technology (LIST); Alya Bolowich, Luxembourg Institute of Science and Technology; Michael Saidani, Luxembourg Institute of Science and Technology; Elorri Igos, NOBATEK/INEF4.

As more sectors of the economy increasingly rely on information and communications technology (ICT) solutions, the environmental impacts from the production of these equipment must be considered. One such sector, precision agriculture, is lacking information in large life cycle inventory (LCI) databases that are often used to develop inventories. Additionally, equipment related to connectivity solutions (5G, LoRaWAN, …) that are required for precision agriculture is also lacking from these databases. As a result of the COMMECT project, a Horizon Europe project aiming to implement connectivity solutions for agricultural and forest activities in rural remote areas, an LCI dataset has been developed of different sensors, weather stations, and connectivity solutions, among others, that allows for the environmental impact assessment of these equipment. The project's five living labs provided data related the brands and models of various ICT equipment. Using this information, an extensive Internet search was made to find main components of the equipment, notably their weight or surface area. This research prioritized data from existing, peer-reviewed life cycle assessments (LCAs); several studies were found, but the LCIs were often not readily usable or were partially published. Other sources of information included scientific literature containing similar LCI data or publicly available manufacturing data of the brand or similar brands. Research into the main components that make up a certain type of ICT equipment to best understand the materials required was also conducted (e.g. main material for a sensor's cathode). This poster will show how such data was collected and will present the LCA results in the form of bar charts and/or Sankey diagrams for select equipment. This LCI dataset is expected to be published in an open-source journal so other LCA practitioners can easily use the data either as-is or tailored to their needs. The dataset will be published both in Excel format and as Brightway packages, making it simple to use in other projects. Encountering semi-published, semi-transparent LCI data is a hassle for many LCA analysts, and such an effort adds data availability and transparency to the growing body of knowledge surrounding not only precision agriculture and connectivity but also to the incorporation of ICT solutions in many sectors.

4.04.P-Mo044 LCA of Digital Solutions for Municipal Services - The Case of three Waste Collection Systems

Birgit Brunklaus, RISE Research Institute of Sweden; Yoon Lin Chiew, Research Institute of Sweden RISE.

More and more digital solutions are implemented on a municipality level. The potential to reduce time and reduce climate impact seems to be at hand. However, are digital solutions able to reduce time and climate impacts in general? The aim of this study is assessing the carbon footprint of digital solutions in three waste collection systems: Waste collection in the city centre, Textile collection and Recycling stations. The functional unit is one year of waste collection service with digital solutions (IoT). The climate impacts are allocated to different actors in the waste collection chain. The reason for that is to elaborate on the service part and the consumption part of the service. Therefore, an actor based LCA method is used to discern the climate impacts from the digital service, the collection service, and the citizen. The results for all three types of waste collection system show that the carbon footprint of the digital solution is neglectable. On the other hand, from the operator's feedback, the operation time is saved in waste collection service, that can be used for providing a better service, while the major climate reduction cannot be reached through using recycled material for the plastic bags for city waste collection, as well as more efficient transport. The results also show that in both the textile waste collection and the recycling stations services, the major climate impacts come from transport of the citizens to the collection system. Instead of reducing climate impacts, the digital solutions for municipal services lead to better service for the citizens.

4.04.P-Mo045 Life Cycle Assessment Of Printed Electronics - A Case Study Of Three Pilot Applications

Lotta Hepo-oja, VTT.

The electronics industry generates significant environmental impact, e.g. via an increasing amount of electric and electronic waste, great demand for critical raw materials, and high energy consumption during manufacturing and use. The EU requires all industries to achieve the ambitious goals of the EU Green Deal, Circular Economy Action Plan (CEAP) and industrial strategy for reduction of energy and material consumption, and utilization of circular value chains. To meet these goals the electronics industry must primarily decrease its specific environmental burden by shifting from fossil-based materials to bio-based materials, decreasing use of (critical, rare, harmful, and valuable) metals, utilizing energy-saving additive manufacturing processes and developing miniaturized and integrated components.

It is expected that the change to bio-based materials and low-energy manufacturing processes will decrease the environmental impacts of printed electronics. The inherent need for metals might still show as high impacts in categories such as use of natural resources. This study is part of a three-year EU project SUSTRONICS which aims to become the European flagship project for sustainable electronics by demonstrating how electronics industry can benefit from sustainable materials and manufacturing. This study is expected to add valuable knowledge on the sustainability of printed electronics for technology developers in the future.

The sustainability of printed electronics will be assessed using life cycle assessment (LCA). The study will focus on existing bio-based and renewable substrate materials together with conductive inks used for printing as well as adhesive biomaterials to understand their environmental impacts and guide technology development within the project. The study will be performed on three specific pilot applications where the focus is in transforming existing electronic products into environmentally friendly alternatives while maintaining the device functionality. The chosen pilot applications are: 1) embedded electronics for EEG monitoring, 2) wearable health monitoring and 3) sustainable dashboard for automotive. The assessment is carried out in three stages, for three generations of pilots. Preliminary results for 1st generation pilots are expected by August 2024. Results for the final 3rd generation pilots are expected by the end of the project in 2026.

4.05 - LCA-Assisted Decision-Making in Circular Packaging Systems

4.05.T-01 Life Cycle Assessment of Circular Flexible Plastic Food Packaging Collected from Businesses through Reverse Logistics

Sophie Huysveld, Ghent University; Arnaud Hauwaerts, Ghent University; Anna-Sophie Haslinger, Ghent University; Trang Thuy Nhu, Ghent University; Jo Dewulf, Ghent University.

Background and Purpose: A challenge towards closed-loop recycling of flexible plastic food packaging is the separation of post-consumer food-contact grade materials (FCMs) from non-FCMs, which are generally collected as a mix. Moreover, this packaging is often comprised of multi-material multilayers (MuMu), which pose huge challenges for recycling. As the current waste management of MuMu leads to a loss of resources, this research investigates the environmental benefits of a new value chain of circular flexible plastic food packaging for businesses, with reverse logistics collection, advanced recycling technologies and mono-material multilayer (MoMu) packaging design.

Methods: A life cycle assessment was performed focusing on the comparison of a basket of products, i.e., 10738 m² FCM laminates, 979 kWh electricity and 6808 MJ heat. In the innovative case, FCM packaging includes a PE-based MoMu structure, are collected at end-of-life (EOL) through reverse logistics and recycled with delamination, deinking and deodorization into MoMu with 50% recycled PE. The baseline case includes collection of MuMu FCM packaging at EOL, through a combination of selective plastic waste and mixed residual waste collection, followed by either incineration with energy recovery or landfilling. All data were collected from industrial and academic partners in the H2020 project “Circular FoodPack”. The Environmental Footprint method v3.1 was used for the impact assessment.

Results: Preliminary results show that, overall, the innovative case performs worse than the baseline case (except for acidification). Food laminate production is the major contributor in both cases, due to virgin material use, followed by delamination and deinking in the innovative case. Although MoMu laminates contain recycled PE, they still contain much virgin materials as they are thicker than MuMu. Delamination and deinking have a low recovery rate, thereby sending residues to incineration. Transport’s contribution is higher in the innovative case, but it does not play a key role. A critical analysis of the results and scenario analyses will be performed to investigate the effect of modelling assumptions.

Conclusions: The preliminary findings of this study show that advancements in collection, sorting and reprocessing should be combined with improved MoMu packaging design (thinner and/or higher recycled content) to improve the environmental performance of circular flexible food packaging.

4.05.T-02 Terrestrial Characterization Factors for Microplastics Ingestion and Additives Release in the Terrestrial Compartment: From Experimental Data to LCIA

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1. Background and purpose

Polyhydroxyalkanoate (PHA) and polylactic acid (PLA) are plastic biopolymers (BPs) which can be combined to potentially substitute petrochemical plastics (e.g. polypropylene (PP) and low-density polyethylene (LDPE)). To quantify their environmental impacts, most of Life Cycle Assessments (LCA) of conventional plastics have ignored mismanaged plastics, both due to losses at the production stage and poor end-of-life (EoL), underestimating their long-term effects. This work aims to develop the correspondent CFs for both biopolymers and petrochemical ones released to the terrestrial compartment.

2. Materials and Methods

The calculation of characterization factors requires the previous calculation of fate (FF), effect (EE) and exposure (XF) factors.

FFs were developed through an experimental study of the accelerated photooxidation of 5 BPs samples; EF were calculated based on literature data on the ecotoxicological effects of the ingestion of microplastics and additives; and XFs were derived based on literature data which estimate the proportion of plastics that remain in the terrestrial compartment.

3. Results

The developed FFs depend on the selected location rather than the polymer conformation, the EFs depend more on the additives present in the samples than on the ingestion of microplastics, and the XF is the same for all of them and equal to 0.7 since the assumption that 70% of the microplastics deposited in the terrestrial compartment remain there.

The CFs of the BPs do not differ significantly based on their conformation (% PHA and PLA). For additives, the CFs are 3 to 4 orders of magnitude higher than microplastic ingestion, reflecting the higher environmental risk of additives in the terrestrial compartment.

And concerning the aquatic compartment, the CFs developed by other authors for the ingestion of PP and LDPE film fragments and the EFs for additives are 8 and 3 orders of magnitude higher than ours, respectively, which is consistent with the higher mobility and accessibility of plastics and additives in the aquatic compartment.

4. Conclusions

The factors are lower than in the aquatic compartment, so it is relevant to consider them to have a holistic picture of the impacts of mismanaged plastics and not to overestimate impacts in the aquatic compartment. Besides, the factors for BPs do not differ significantly from those for petrochemical plastics, so the best environmental performance of BPs requires proper EoL management.

4.05.T-03 Circularity Assessment of Reusable Packaging Developed in the BUDDIE-PACK Project

Justine Gloz, Industrial Technical Center for Plastics and Composites (IPC); Ewen Rondon, Industrial Technical Center for Plastics and Composites (IPC); Maryam Hoseini, The University of Sheffield; Stuart Walker, The University of Sheffield,; Alex Newman, The University of Sheffield,; Rachael Rothman, The University of Sheffield,; Catherine Rothman, Industrial Technical Center for Plastics and Composites (IPC).

Over recent years, numerous Life Cycle Assessments (LCAs) analysing reuse systems and comparing them to existing single-use systems have been published. Whilst useful for assessing when and how switching to a reusable system can be a better option to tackle issues such as global warming or resources depletion, it is difficult to draw conclusions from them in the short and long term to make strategic decisions on the european adoption of reuse, as they suffer from a lack of real operational data and methodological reference frames. The BUDDIE-PACK project aims to develop business-driven systemic solutions for sustainable plastic packaging reuse schemes in mass market applications. To assess their sustainability, two-step (screening then full assessment) environmental, economical and social Life Cycle Assessments are performed on the five reuse use-cases developped in the project.

The LCA screenings include an analysis of the contributing factors, along with the assessment of Break-Even Points (BEP) of reusable systems, i.e. the number of uses necessary to be better than a single-use alternative. They follow the ISO 14044 standard, as well as the general Product Environmental Footprint guidelines. As there is no Category Rule for packaging, the ADEME method for packaging comparative LCA is used. Data coming from project partners include weight, material, production process of packaging or washing consumptions. Assumptions were made for reusable solutions that are not yet comercialised. Literature values were used for plastic recycling process. Other data comes from the Ecoinvent 3.9 database. All the impact categories from EF3.0 are evaluated for the contributors identification. Design guidelines are based on the BEP analyses performed for climate change and water consumption.

The results for the five use-cases evaluated show that the main contributors are packaging material production, reverse logistics and washing, and consumer transport for Business-to-Consumer solutions. Those are the main opportunities to lower the BEP with single-use alternatives, but also the steps with the most data gaps.

In conclusion, LCA screening studies enabled the BUDDIE-PACK partners to identify the main hotspots of each use-case. Future work will collect the remaining data (real reuse rate, real mass of the packaging, materials production, addtionnal compared solutions...) to assess the environmental, economic and social relevance of the developed reusable packaging.

4.05.T-04 Reusable Rice Packaging: An Extended Comparative Life Cycle Assessment

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Background and purpose: Single-use packaging encompasses multiple environmental problems, such as the requirement for primary materials and the impacts caused by emissions during the lifecycle process. To limit these environmental impacts, recycling processes have been developed to close the life cycle of this plastic packaging. However, from a circularity point of view, recycling is not the most preferred circularity strategy. Reuse is deemed much more beneficial as this avoids the environmental impacts that can be caused by recycling processes. However, the traditional single-use packaging designs are not optimal for reuse. Hence, new reusable packaging designs are required. To ensure that such new reusable design is more sustainable than the traditional linear design, it does not only need to be more circular, its environmental impact needs to be lower as well. In addition, a different type of packaging can impact its function as well, being the preservation and transportation of food.

Methods: This study provides the results of an extended life cycle assessment of a specific reusable rice packaging design. The extended assessment incorporates both circularity aspects, using a material flow analysis, as packaging-related food losses and wase (using the food-to-packaging ratios).

Results: Incorporating the whole life cycle and losses in the distribution, use and reuse preparation phase, the reusable rice packaging designs could be reused five times. The reusable rice packaging scored better on the included circularity indicators, but worse on the environmental impact indicators. The high-food-to-packaging ratios point to the importance of minimizing food waste by an optimized packaging design. The sensitivity analysis identifies the reuse and reusable rate as the main parameters influencing the results.

Conclusions: While reusable packaging designs may have a higher environmental impact in their production processes, prospective extended life cycle assessments can identify how these designs can still outperform single-use packaging designs. This can steer product design in the most circular and sustainable direction.

4.05.T-05 Assessing Complementarity of Polymer Recycling Technologies Through Life Cycle Assessment

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To accelerate the pace for more circularity an enabling legislative framework and the complementarity of recycling technologies are crucial. The EU's target for recycling plastics has been tightened and the new target for recycling separately collected plastic packaging is 55% by weight in 2030. HydroPRT is a novel advanced recycling technology that complements mechanical recycling and can be used to prevent the improper disposal of post-consumer plastics. This paper presents a life cycle assessment that evaluates the complementarity of HydroPRT, mechanical recycling, and incineration with energy recovery. Using the ReCiPe 2016 impact assessment methodology, the results demonstrate that chemically recycled plastic using HydroPRT can replace virgin plastic, contributing to a 42% reduction in Climate Change impacts as a complement to mechanical recycling. Furthermore, a sensitivity analysis showed that collection rates of over 29% will deliver a saving in carbon emissions compared with the current state of recycling within the UK. This presents new insights into the environmental implications that arise as a consequence of the deployment of advanced recycling and highlighting its benefits in the context of complementarity for this technology.

4.05.P - LCA-Assisted Decision-Making in Circular Packaging Systems

4.05.P-We069 Environmental Assessment of Reusable Take-Away Packaging: A Holistic Perspective

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The paper addresses the problem of disposable take-away packaging, such as food containers, mugs, lids, etc. Use of these items continuously increases world-wide and while they fulfill a need, the lifespan across which they do so is too limited to justify the consumption of resources necessary for their production. In line with the 2020 Green Market for Products and the Sustainable Products Initiative (SPI), various proposals for policy and legislation to tackle the issue of disposable take-away packaging have been presented by the European Commission recently [1]. For instance, new national regulations have been launched in Sweden, which require reusable packaging to be offered at all establishments that serve take away food, with the aim of reducing the use of disposable packaging.

To assure the recirculation of reusable packaging in the economy, deposit return system has been considered. Deposits for the reuse of take-away packaging have existed for a long time in other countries, however, such initiatives have appeared in the Swedish market relatively recently and at the local level. Here, the debate centers around the environmental impact of the use of reusable take away packaging from all processes that are required from the manufacture of reusable packaging to the (potential) number of rotations, transport and redistribution between actors, cleaning, as well as waste after use.

This paper will present the results of the study outlining a comparison of reusable packaging types, as well as recommendations for applying the reusable packaging systems

4.05.P-We070 How Environmentally Sustainable is Flexible Plastic Packaging when Shifting from Multi- to Mono-materials?

Trang T. Nhu, Ghent University; Sophie Huysveld, Ghent University; Naomi Muindi, Ghent University; Nicolas Mys, Amcor; Jo Dewulf, Ghent University.

Flexible plastic packaging has become the fastest-growing form of packaging but also one of the predominant waste streams raising environmental concerns due to challenges in sorting and recycling multi-material multilayer (MuMu) laminates. Consequently, a shift from MuMu to mono-material multilayer (MoMu) structure, following the Design For Recycling (D4R) initiative, for food has been recommended. This work will address if this shift is environmentally beneficial, using a cradle-to-grave Life Cycle Assessment (LCA) on duplex and triplex structures. The stages and impacts associated with food were excluded. The functional unit (FU) was 1 m2 of laminate designed for food. Inventory data came from onsite collection, ecoinvent v3.9 database and the literature. Environmental Footprint v3.1 and Circular Footprint Formula methods were implemented.

The analysis first presents fossil resource use (FRU), climate change, particulate matter and photochemical ozone formation contribute the most (>80%) to the endpoint single score; hence, these impact categories are discussed. Amongst packaging-related stages, raw material production is the largest contributor to the environmental impact compared to the others: laminate conversion, distribution, packing and end-of-life (EoL) treatment. Shifting from MuMu to MoMu laminates can significantly reduce the environmental impacts (27-52% for duplex and 16-49% for triplex), mainly explained by a switch in raw fossil materials used in laminates (from polyamide, PA, and polyethylene terephthalate, PET, to polyethylene, PE) and EoL treatment (from incineration with energy recovery to mechanical recycling). This is valid regardless of whether MoMu is heavier (duplex) or lighter (triplex) than MuMu for a similar FU. The exception is FRU which is driven mainly by the mass contribution of fossil polymers to the laminates.

Rooms for improvement were investigated. Firstly, switching from fossil- to bio-based PE is currently not worth it unless ethanol production from biomass becomes more environmentally sustainable. Switching to renewable sources for electricity production (i.e. wind, solar energy) or lowering the material losses in the laminate conversion can benefit but is limited due to a smaller share of this stage than raw material production. Further research on the advanced EoL technologies (e.g. purification and/or chemical recycling tested for MuMu or MoMu) which enables closing the loop, is recommended.

4.05.P-We071 Closing the Loop of the Beverage Carton: A Life Cycle Assessment on the Chemical Recycling of the Polyethylene-Aluminum (PolyAl) Fraction

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Beverage carton (BC) is a multi-material multilayer packaging, comprised of paper, low-density polyethylene (LDPE), and aluminum. While the paper fraction of BC is recycled, most of the LDPE-aluminum fraction (PolyAl) currently faces disposal in waste-to-energy (WTE) plants across Europe. Chemical recycling (CR) via pyrolysis emerges as a potential solution to recycle PolyAl, thereby contributing to the circular economy (CE). However, as an emerging technology, CR requires demonstrating its environmental advantages over current waste management methods. This study aims to evaluate the potential environmental impact of CR via pyrolysis of the PolyAl waste fraction of BC using an attributional life cycle assessment (LCA) and the European Commission’s Environmental Footprint method (v3.0). The functional unit was defined as the management of one ton of PolyAl waste after separating the paper fraction at the pulpers. Process flow schemes were defined for the newly developed PolyAl closed-loop recycling scenario and for the reference scenario, which is based on 2020 data, encompassing WTE in cement kilns and incineration plants, and landfilling. Although the reference scenario does not fully represent current PolyAl waste management, where a portion is mechanically recycled, it was selected due to data availability and the predominance of these practices in 2020. Material flow analysis for the newly developed value chain shows that around 42% of one ton of PolyAl waste can be chemically recycled into naphtha. This value chain and its marketable products will be compared to the reference waste management of PolyAl. Climate change impact results for the reference waste management reveal that when PolyAl waste substitutes fossil fuel for energy applications in cement kilns, benefits outweigh burdens. However, unlike CR, which produces recycled naphtha that can be further processed to produce LDPE for BC, WTE does not align with a CE, as valuable materials do not return to material applications. Thus, initial conclusions highlight first the need for CE indicators to demonstrate the advantages of CR and second the importance of considering the potential of recycled naphtha to substitute virgin fossil-based naphtha. The anticipated LCA results for CR are expected to pinpoint key areas for environmental improvement compared to the current waste management value chain. These findings are intended for presentation at the SETAC conference in October.

4.05.P-We072 Assessment of Sustainable Packaging for Thermosensitive Products Transport

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The transportation sector, as the fourth-largest contributor to global greenhouse gas emissions, accounted for 15% of total emissions in 2019. This project aims to optimise the fish transport chain, focusing on enhancing logistical efficiency and reducing reliance on active cooling systems in vehicles. To do that, the present project will develop a reusable package, partially made from recycled materials and with its own cooling system. This project aims to compare the environmental performance between the non-reusable baseline packaging and the newly expanded polypropylene (EPP) developed packaging. The study will focus on deep-frozen fish packaging, which currently uses plastic bags enclosed in a cardboard box. The goal is to ascertain the number of reuses needed for the EPP box to offset the environmental impact of the baseline packaging, thereby supporting seafood industry decision-makers and contributing to European Commission sustainability goals.

Using the life cycle assessment methodology based on ISO 14040-44, this study compares the environmental performance of the baseline box with the new EPP box. The functional unit (FU) is the production of one box to transport 10 kg of fish, and the system boundaries follow a "cradle to grave" approach. The end-of-life stage assumes full recycling of the EPP box, while various scenarios (full-landfill, full-recycling, and Portuguese reality) were assessed for the baseline box. The impact assessment was performed using SimaPro software, with primary data from Polipop and Riberalves companies, and secondary data from the Ecoinvent database. The ReCiPe Endpoint Hierarchist perspective method was employed, considering three endpoint categories.

The study's results are divided into linear and circular economy approaches. In a linear economy, where only the environmental impact of producing 1 box to fulfil the UF was evaluated, the new EPP box’s environmental impact was higher than the baseline box. However, in a circular economy, the EPP box became the better option in all damage categories when reused at least 3 times. Upstream processes contributed most to the environmental impacts, while downstream processes had positive impacts on the environment.

This study concludes that the new EPP box was better than the baseline when reused in a circular economy approach. Employing reverse logistics and reusing the boxes, can reduce environmental impacts by minimising the raw material production for producing new boxes.

4.05.P-We073 Food Packaging, Wasted Food? A Critical Look at LCA Methodologies in the Food Packaging Industry
Musharof Hussain Khan, Natural Resources Institute Finland (Luke).

The assessment of food packaging systems through life cycle assessment (LCA) is crucial for understanding their environmental impacts. The current Product Environmental Footprint (PEF) guideline is good starting point to enhance harmonised assessment of the environmental impacts of packaging materials and their supply chains and recovery but often overlooks consequential indirect impacts, such as food waste resulting from packaging performance. This study aims to address this gap by comparing the environmental impacts of food packaging systems using both attributional and consequential LCA methodologies. Attributional LCA confines its scope to the direct emissions and resource use associated with the production, use, recovery and disposal of packaging materials. This approach can provide a limited view by neglecting downstream effects, such as potential changes in food waste patterns due to packaging efficiency and performance, since the main role of packaging is the prevention of food waste. This role of packaging needs to be included in the LCAs of food packaging to include the indirect and long-term effects of packaging, providing a more comprehensive understanding of its environmental performance. This research investigates two cases of food packaging systems: one focusing solely on the environmental impact of the packaging materials itself, and the other encompassing the indirect environmental impact arising from potential food waste caused by the packaging material's performance. This study employs a harmonized framework to assess the environmental impact of food packaging systems, focusing on their contribution to relevant impact categories, such as global warming, abiotic depletion, acidification, and eutrophication. The findings advocate for a revised approach in LCA guidelines, emphasizing the importance of considering food waste consequences in the environmental evaluation of food packaging systems. This harmonized methodology aims to better inform policymakers and industry stakeholders, guiding the development of sustainable food packaging solutions that not only address material impacts but also mitigate food waste. This abstract contributes to the ongoing discourse on LCA methodologies, promoting a comprehensive evaluation framework that can drive more effective environmental policies and innovations in the food packaging sector.

4.06 - An Era of Change in Sustainable Textiles: Robust Data-Driven Life Cycle Assessment

4.06.T-01 Life Cycle Sustainability Assessment (LCSA) of Jeans Stone Washing: Pumice Stone vs Reusable Plastic Stone
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The textile sector has significant environmental impacts, necessitating monitoring and reduction strategies. This study focuses on the wet process of denim manufacturing, which uses chemicals and mechanical friction with pumice stones to achieve the desired fabric feel and typical worn-down look, but it generates sludge waste. A synthetic abrading stone is tested as an alternative, being reusable, fully recyclable, and not producing sludge. The study particularly examines the wet process effluents impacts on human and eco-toxicity. As part of the CALIMERO project, the sustainability of both wet processes by the company EREKS is assessed using a full life cycle sustainability (LCSA) framework, including LCA, social LCA (S-LCA) and life cycle costing (LCC). The textile's product life cycle is considered out of scope as it is equivalent in both processes.

The LCA follows the Product Environmental Footprint (PEF) with ecoinvent v3.9.1 cut-off as the background database and the Environmental Footprint (EF) 3.1 for impact characterization. The S-LCA evaluates impacts on job creation using the PSILCA database, while the LCC includes net present value, production costs, and externalities based on the European Trading Scheme.

Foreground system data was provided by EREKS and the life cycle inventory created accordingly. Chemical inputs production was modelled as per MSDS substance composition, while for the effluents toxicity assessment, the corresponding degradation products, their characterisation factors and their partitioning were based on literature.

Regarding preliminary results, the aggregated single score of the synthetic stone process is 76% lower than the conventional one. Gains are due to the substitution of potassium permanganate and the elimination of the "after pp-spray" step. Further contributions come from the elimination of pumice stone, the reduction of 108 kg of chemical inputs per washing cycle and the avoided sludge disposal. At impact category level, the alternative washing has lower climate change impact by 73%. Lower chemical inputs decrease human and eco-toxicity impacts by 81% and 91%, respectively, replacing pumice stone cuts land use impacts by 85%, and using less water per cycle reduces water use impacts by 82%.

Social and economic assessments of both processes will be finalized by June 2024 and will provide a holistic evaluation of the sustainability of the denim wet process, while contributing to the development of the LCSA framework.

4.06.T-02 Integration of the Circular Footprint Formula with the Material Circularity Indicator to Measure the Textile Circularity
Laura Morvidoni, Polytechnic University of Torino; Giuseppe Picerno, Manteco SpA; Isabella Bianco, Polytechnic of Turin.

Over the past ten years, many industrial sectors have initiated an ecological transformation in order to achieve the goals of sustainable development. This shift towards an optimised circular economy involves not only the introduction of zero-waste practises and recycling methods, but also the adoption of sustainable practises that promote circular design. The introduction of the new harmonised EU Product Environmental Footprint (PEF) methodology, which provides for a PEF score that could be used for marketing purposes, aims to promote specific rules, comparability and eco-design. This emphasises the importance of cooperation between the value chains and the importance of raising awareness of sustainability issues among market participants.

This work proposes to close existing gaps in the Circular Footprint Formula (CFF) with reference to the specific Product Environmental

Footprint Category Rules for Apparel and Footwear (PEFCR A&F), which are currently under revision. Among the end-of-life modelling challenges, the focus has been on the material component of the formula. It has been shown that the quality factor for recycled materials has some weaknesses. Therefore, a theoretical model was developed that considers the frequency of recycling cycles and is based on a technical property of the raw material and not on an economic definition.

The CFF is a complex but efficient formulation compared to other allocation models due to the many parameters involved. Looking to the future, challenges remain in relation to the sector's environmental impact, but there are also opportunities through the use of complementary indicators to enhance the supply chain transparency and the implementation of circular business models. The use of the Material Circularity Indicator (MCI) shows the circularity of the product and integration with the CFF could open up promising prospects for a more comprehensive impact assessment.

The results presented concern the application of the proposed new technical formulation and the MCI in relation to a finished product of the Italian textile company Manteco®, which is considered as a case study. By using a broader definition of impact, end consumers were able to make more informed decisions about sustainability. The establishment of guidelines by the EU for environmental impact assessments and circular economy measures could have a significant impact on corporate responsibility and the overall direction of the textile industry.

4.06.T-03 An Evaluation of Textile Waste Utilization Methods Using the Safe and Sustainable by Design Framework

Diego Peñaloza, Research Institutes of Sweden RISE.

The environmental impacts of the fashion industry have been increasing steadily since 2005 due to increased consumption and a shift to more synthetic fibers, trends that are projected to keep rising if business-as-usual scenarios continue. As a response, multiple technologies have been developed to mitigate these impacts. Still, several of these technologies have their own environmental challenges, sometimes creating new impacts in different impact categories.

To provide knowledge concerning the environmental aspects of textile waste utilisation routes , the following work was performed. First, the existing literature was screened for any type of results that could provide indications of the environmental performance of the utilisation routes within the scope of the project. Then, a methodology based on the Safe and Sustainable by Design (SSbD) framework was developed for evaluating selected utilisation routes. The design principles proposed in SSbD were adopted, and a set of indicators for these principles were selected. The scoring system was applied based on the knowledge extracted from the literature review. Finally, this preliminary result was validated by the technical experts in tExtended via workshops, and adjustments were made based on the discussions and feedback.

The literature review shows that methodology applied varied significantly across the studies, so making comparisons and using their results for quantitative assertions as part of the scoring is not possible and the scoring system applied to evaluate the utilisation routes needed to be more qualitative in nature.

The overall results from the scoring were aligned with the waste management hierarchy, favouring re-use routes over recycling routes. The results also point out specific challenges with each route, as well as data gaps in terms of environmental aspects of specific technologies and processes.

4.06.T-04 Environmental Viability of Recycling Flame Retardant Cotton Workwear

Kiia Silvennoinen, Finnish Environment Institute; Susanna Horn, Finnish Environment Institute; Helena Dahlbo, Finnish Environment Institute.

The EU member states are obliged to set up separate collection for textile waste from the beginning of 2025 and solutions for recycling these textiles are needed. Besides many other difficulties, the use of chemical finishes and dyes hinder the recycling potential of textile waste as chemicals and dyes are often unwanted in recycled products and complicate the current recycling processes. For a large share of the chemicals and dyes used in textile manufacturing, the effects they have on the chemical recyclability of the products is not fully understood. To enable chemical recycling of chemicals containing textiles, different treatments are required. A group of rather homogenous textile waste for recycling with large and constant volumes is occupational workwear that can be collected, sorted and treated in bulk. The treatment causes environmental impacts which may even outweigh the benefits of recycling. Therefore, systemic assessments of the life cycle impacts of alternative end-of-life scenarios are required to identify the environmentally most promising pathways for increasing the circularity of workwear.

To support the development of circularity in workwear, this study investigates the chemical recycling potential of cotton workwear containing flame-retardant (FR) chemical and dye residues from an environmental perspective. The main research question of "how do the FR chemicals and dyes used in the textile affect the environmental performance of chemical recycling of textiles" is studied through life cycle assessment (LCA) of three different recycling scenarios and comparing them to the base case of textile waste incineration. The scope of the LCA covers the full life cycle of the garment but focuses on the novel chemical recycling process (lab-scale) and material substitution.

Results of the study are expected in the summer of 2024. They will provide information for decision-making on which of the studied recycling scenarios seems the most environmentally viable for cotton FR workwear – or if the resource use in the treatment phase even outweighs the benefits of chemical recycling and other circularity options should be focused on. The results can also offer perspective to textiles impregnated with other chemicals.

4.06.T-05 Lighten the Load – Reducing the Carbon Footprint of Safety Boots

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Safety boots are everywhere. They are the quintessential personal protective equipment (PPE) across industries from construction to (petro)chemicals, worn daily by millions of people. The strict protective property requirements and the need for comfort for the wearer limit the range of materials that can be used. So far, the safety boots' environmental performance has been largely ignored in the design and manufacturing phase.

This study, in collaboration with a Norwegian workwear manufacturing company providing real-life data, quantifies the environmental performance of the current boots, identifies hotspots, and investigates possible improvements. This led to the inclusion of environmental considerations in the early design stages, creating a better-performing boot.

First, we establish a baseline cradle-to-grave LCA for a representative safety boot and then compare it to alternative boot designs that deploy circular strategies. Replacement with alternative or bio-based textile materials, and lifetime extension are explored. The functional unit is one pair of safety boots that meets the offshore petroleum industry standard (NORSOK), worn on average 6 months in harsh conditions before it is discarded.

The reference and alternative safety boots and the LCI were developed with the manufacturer, supplemented by supplier interviews and literature data. The focus is on Global Warming Potential (GWP100) and the Ecoinvent 3.2 database in SimaPro version 9.3.0. was used for the LCA.

The carbon footprint of the reference boots is 35 kg CO2e, of which 60% is from the leather-based components. A redesigned boot with alternative materials reduces the emissions by 50%, while switching to bio-based plastics did not significantly improve the GWP results further. Boot redesign to extend the use time to 10 months yields an additional 31% emission reduction.

This study highlights that significant improvements in carbon footprint are possible when LCA is applied in the early design stage, even for products with strict technical performance requirements. A more holistic view, by considering additional environmental impact categories, will allow for better-informed decision-making on, e.g., (bio-based) material selection. However, obtaining high-quality and transparent environmental data on alternative textile materials from the suppliers is essential but very challenging.

Additional work beyond LCA is required for a circular safety boot value chain.

4.06.P - An Era of Change in Sustainable Textiles: Robust Data-Driven Life Cycle Assessment

4.06.P-Mo046 Life Cycle Assessment of Chemical Recycling of Mixed Synthetic Textiles – A Grave-to-Gate analysis

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Background and Purpose
Global textile production is increasing, consuming large volumes of fossil carbon and generating large volumes of textile waste. Most of it is currently not recycled. A common combination of synthetic textile fibers is polyester and elastane, which can often be found in, for example, sportswear. Within the EU and elsewhere, emerging textile recycling technologies are being explored as a response to national and international calls for sustainable and circular textile production and waste management practices. Monomer recycling, where the different synthetic polymers are depolymerized to monomers through glycolysis and separated for further treatment into new polymers, is one proposed solution.

The goal of the study is to assess the environmental footprint of approaches to recycling a mixed synthetic textile waste flow consisting of polyester and elastane to evaluate whether the process is environmentally beneficial in comparison to a business-as-usual case.

Methods
We assess three scenarios for how synthetic textile fibers can be produced and postconsumer waste treated. Two scenarios represent different process set-ups for recycling the mixed synthetic waste, and the third scenario represents a business-as-usual case where the fibers are incinerated for energy recovery as waste treatment while new polymers are produced from fossil raw material.

The proposed process designs for chemical recycling have been tested in laboratory scale to generate chemical data as input for scaling up the model of the first two scenarios. Life Cycle Assessment (LCA) is performed using scaled-up primary data and commercial data for background processes in an LCA for Experts (Gabi) environment. The LCA assesses the scenarios in a grave-to-gate system boundary.

Results
Comparative quantitative measures for environmental footprint of the three scenarios will be presented with a focus on climate changing emissions. Preliminary work suggests that recycling of textile blends, such as polyester/elastane, with recovery of all material components is interlinked with emissions, such as CO2, that surpass the use of virgin materials, which challenges the notion that material recycling is always a good idea.

Conclusions
The results are intended to inform policy makers about the merits of recycling and process designers about hotspots for environmental impacts of this system to foster informed decisions that will benefit sustainable waste treatment of textiles in the EU.

4.06.P-Mo047 Environmental Impacts of the Clothing Use Phase: Influence of the Washing Efficiency

Tian Xia, University of Lille - ENSAIT; Romain Benkirane, University of Lille - ENSAIT; Anne Perwuelz, University of Lille – ENSAIT.

Existing life cycle assessments of clothing show that the use phase contributes significantly to resource use and overall environmental impacts, which not only consist of water, energy, and chemicals consumption but also chemicals and micro-plastics release, finally aggravating greenhouse gas emissions and water toxicity. The energy use and greenhouse gas emissions in the use phase may be attributed more than the manufacturing phase for clothing washed frequently.

To reduce environmental impacts, political regulations such as energy labeling are implied in the assessment of most household washing machines. Meanwhile, the washing performance must meet certain limit values. The common strategy of manufacturers is to prolong the washing time and reduce the temperature, as the temperature is the main factor of energy consumption and may aggravate clothing damage. However, the washing frequency and parameters are determined mainly by consumers, use behavior can be more influential to total environmental impact. Consumers might not use energy-efficient programs with long wash cycles since they're inconvenient and some consumers don't believe long cycles are energy-saving, on the contrary, they tend to choose short cycles with higher temperatures or more detergent to meet their needs for stain removal and good hygiene performance.

Therefore, to explore better washing performance with less environmental impact washing procedures, this study employed response surface methodology to design an experiment of 15 programs to find the relationship between the washing parameters and washing efficiency in both short-term and long-term washing, environmental impacts of different programs are recorded and characterized through Life Cycle Assessment tool Simapro. 3 consumer-oriented parameters are chosen: load, detergent concentration, and temperature. Standard ballasts and cotton test strips soiled with IEC carbon black and mineral oil are used in this experiment to test the washing efficiency and evenness. Commercial detergent with an adapted formulation and commercial washing machine are used to simulate household laundry.

The washing efficiency and environmental impact of 15 different washing parameters will be given and compared. Optimized washing parameters for better washing performance with less environmental impact will be chosen by the optimum response of performances, which provides suggestions for consumers on parameter selection during the laundry process and washing machine manufacturers on program settings.

4.06.P-Mo048 Optimisation of a Textile Washing Process Based on Life Cycle Sustainability Assessment Results

Maura Camerin, Luxembourg Institute of Science and Technology (LIST); Antonino Marvuglia, Luxembourg Institute of Science and Technology (LIST); Alexandre Betrand, Luxembourg Institute of Science and Technology (LIST); Valentin Jacoutot, Techtera; Juliette Jaupitre, Techtera; Merlin Alvaro-Morales, Technical University of Denmark (DTU); Milena Alvaro-Morales, Neovili; Enrico Benetto, Luxembourg Institute of Science and Technology (LIST); Thomas Schaubroeck, Luxembourg Institute of Science and Technology (LIST).

EU directives identified the textile sector as a key area for environmental, economic, and social assessment and process optimization, particularly in relation to water and energy use, core focus of the CALIMERO project.

We are analyzing the high-temperature washing process of "Teintures et Impressions de Lyon (TIL)", which involves the removal of cellulose from fibers, a water and energy-intensive process. To reduce the environmental burden of the process, we consider two aspects: (1) analysis of LCSA results of the current scenario and (2) process optimisation based on the previous step.

Considering the first aspect, we include Life Cycle Assessment (LCA), Life Cycle Costing (LCC), and Social Life Cycle Assessment (S-LCA). For LCA, we aim to follow the Product Environmental Footprint approach, based on the inventory data collected from the company TIL for all relevant flows (heat, electricity, water usage). The ecoinvent 3.9.1 database is utilized to cover background processes.

In the second step, namely the optimisation, we exploit the potential to recover heat from the washing water by integrating a suitably sized heat exchanger, which is of main concern. The challenge in this task lies in carrying out an optimisation built not only on thermodynamic properties that lead to calculate the most suitable heat exchange area, but also based on the results of step (1). The goal of the optimization is indeed to find the best solution that minimizes the economic costs and environmental burdens, while providing a social benefit. While considering the LCSA results of step (1), we also add the LCSA of the potential heat exchanger installed in the advanced configuration.

The challenges arise due to the absence of defined datasets for heat exchangers, and in defining the function that assess all the relevant parameters.

To overcome the first issue, a new dataset will be created for the specific heat exchanger, using data from relevant literature. For the second, a technoeconomic and social function will consider standard economic indicators, job creation potential and environmental CAPEX and OPEX ", which correspond respectively to the additional life cycle impacts of the heat exchanger for its manufacture & disposal, and avoided operational impacts of the boiler.

The ultimate goal is to achieve the best design condition that results in a reduction in energy and water usage, thereby directly optimize the industrial process and indirectly improving sustainability impacts.

4.06.P-Mo049 The Influence of Recycling Disruptors in Textile Recycling

Valentina Rossi, Technical University of Denmark; Heather Logan, Technical University of Denmark; Anders Damgaard, Technical University of Denmark.

Background and Purpose
Post-consumer garments available for textile recycling will significantly increase soon, but factors such as fibre composition and presence of recycling disruptors (e.g., button and zippers) might affect how much of the collected material can be reprocessed into new one as well as their replacement rate.
Current mechanical recycling technologies cannot process parts of clothes contaminated with metal and non-removable accessories, which need to be removed beforehand, reducing the yield or adding extra purification steps. Nonetheless, studies on textile recyclability often disregard the role of such accessories. This research addresses this gap by highlighting the influence that recycling disruptors have on both the quantity and the quality of the textile material that can be recycled.

Methods
A composition survey was conducted to gather primary data on the presence and number of accessories in different product types (tops or bottoms). Material flow analysis (MFA) is then applied to estimate the share of textile materials lost during the pre-treatment methods required to remove eventual recycling disruptors under two scenarios. Finally, life cycle assessment (LCA) is used to evaluate how accessories potentially influence the environmental benefits of recycling.

Results
Most accessories are placed in the front vertical fold and in the upper part of the front of both tops and bottoms garments. More than half of the top category items and almost all bottoms have minimum 1 accessory, and while most of the tops have between 1 and 4 findings, bottoms have on average around 5.
Preliminary LCA results show that, with regards to climate change, the pre-treatment method influences the overall environmental benefits of the recycling process depending on the extent to which it affects the quality of the output as well as on how much textile material is lost per accessory removed.

Conclusions
Information relative to the presence, amount, and distribution of recycling disruptors is lacking, but these can affect the recyclability of textiles, since they challenge current mechanical recycling technologies, as well as their replacement rate, because the pre-processing method can impact the quality of the textile material. As such, more granular data like the ones provided by this research are necessary to evaluate the role of such design elements, which is

needed to enable a more accurate assessment of the environmental impacts of textile recycling.

4.06.P-Mo050 Lighten the Load – Reducing the Carbon Footprint of Safety Boots

Chibuikem Nwagwu, SINTEF Manufacturing AS; Halfdanarson , SINTEF Manufacturing AS; Christina Meskers, SINTEF Manufacturing AS.

Safety boots are everywhere. They are the quintessential personal protective equipment (PPE) across industries from construction to (petro)chemicals, worn daily by millions of people. The strict protective property requirements and the need for comfort for the wearer limit the range of materials that can be used. So far, the safety boots' environmental performance has been largely ignored in the design and manufacturing phase.

This study, in collaboration with a Norwegian workwear manufacturing company providing real-life data, quantifies the environmental performance of the current boots, identifies hotspots, and investigates possible improvements. This led to the inclusion of environmental considerations in the early design stages, creating a better-performing boot.

First, we establish a baseline cradle-to-grave LCA for a representative safety boot and then compare it to alternative boot designs that deploy circular strategies. Replacement with alternative or bio-based textile materials, and lifetime extension are explored. The functional unit is one pair of safety boots that meets the offshore petroleum industry standard (NORSOK), worn on average 6 months in harsh conditions before it is discarded.

The reference and alternative safety boots and the LCI were developed with the manufacturer, supplemented by supplier interviews and literature data. The focus is on Global Warming Potential (GWP100) and the Ecoinvent 3.2 database in SimaPro version 9.3.0. was used for the LCA.

The carbon footprint of the reference boots is 35 kg CO2e, of which 60% is from the leather-based components. A redesigned boot with alternative materials reduces the emissions by 50%, while switching to bio-based plastics did not significantly improve the GWP results further. Boot redesign to extend the use time to 10 months yields an additional 31% emission reduction.

This study highlights that significant improvements in carbon footprint are possible when LCA is applied in the early design stage, even for products with strict technical performance requirements. A more holistic view, by considering additional environmental impact categories, will allow for better-informed decision-making on, e.g., (bio-based) material selection. However, obtaining high-quality and transparent environmental data on alternative textile materials from the suppliers is essential but very challenging.

Additional work beyond LCA is required for a circular safety boot value chain.

4.07 - Better Data and Modelling for Sustainable Transport

4.07.A.T-01 Accuracy and Sector Consistency in Automotive LCAs: A Balancing Act

David Algesten, Scania Technical Centre; Ida Ritzman, Scania Technical Centre; Venkata Upadhyayula, Scania Technical Centre; Erik Nellström, Scania Technical Centre.

Background and Purpose
Life Cycle Assessment (LCA) methodology is deeply engrained into the sustainability strategy toolbox of environmental conscious enterprises. Companies, including Scania, perform LCAs for four principle reasons: (a) to communicate environmental performance of products with their customers (through externally verified LCA reports or environmental product declarations and enable them to make sustainably wise decisions; (b) fulfil regulatory requirements (e.g., Product Environmental Footprint declarations, Corporate Sustainability Reporting Directive); (c) generate data to facilitate the process of informed decision making on internal research projects like eco and circular design of products; and (d) provide input to Science Based Targets projects initiated by companies.

Sometimes, the outcome of studies is arguable due to multipronged ambiguity (due to factors like choice of impact assessment method and inventory data, etc) associated with current LCA practices. Although unintended, the subjective nature of LCA can potentially lead to misinterpreted conclusions.

Lack of consistency and/or accuracy of LCA studies is a cause of a major concern especially for OEMs of automotive industry. The complexity of automotive products with a highly diverse material composition, and difficulties in building use stage modelling scenarios representative of real world conditions, makes it challenging to always conduct LCAs without compromising on consistency or accuracy.

Methods
To address this issue, on one hand entire automotive sector is rigorously working to achieve the consistency required by streamlining methodological aspects of vehicle LCAs and on other hand, individual OEMs are constantly striving to improve accuracy of their life cycle inventory (LCI) modelling procedures.

Results
In today's talk, we will discuss on two aspects: (a) Scania's approach (OEM perspective) of developing LCI models with high accuracy through increased representativeness, and systematically reduce margin of error while performing vehicle LCAs; and (b) highlights from some ongoing initiatives of automotive sector of tackling the LCA consistency problem.

Conclusions
We conclude our presentation by shedding light on future direction where automotive industry is headed for conducting vehicle LCAs and also highlight potential risks emerging the form of inhibiting accuracy for achieving higher sector consistency.

4.07.A.T-02 Life Cycle Assessment of Bidirectional Charging Equipment for Vehicles Able to Provide Grid Services

Pedro Anchustegui Balner, Chalmers University of Technology; Anders Nordelöf, Chalmers University of Technology; Maria Bernander, Volvo Car Corporation; Mikael Alatalo, Chalmers University of Technology.

Vehicle-to-grid (V2G), feeding power stored in an electric vehicle (EV) back to the grid, can provide benefits to society and EV users alike. Among the potential benefits is the improvement of environmental performance of the energy system as well as the vehicle. Life cycle assessment (LCA) has been commonly used to estimate environmental performance in the automotive industry. However, V2G presents issues for LCA analysis and the allocation of impacts since the system becomes multioutput. As the connection between the EV and the electricity grid, the charging infrastructure

and the changes required for it to enable bidirectionality are explored in this study.
This study focuses on the charging equipment, which consists of an onboard charger and the electric vehicle supply equipment (EVSE). A cradle-to-grave LCA is performed on two comparable systems, one bidirectional and another unidirectional, and both for contributions to climate change and resource use.
The hypothesis is that results will show higher impacts for the V2G-ready system for the manufacturing phase, due to the more complex electronic components required for bidirectionality. However, the performance of V2G-ready system during the use phase could offset this effect due to the difference in charging efficiencies.
The assessment's results highlight the environmental impact derived from having a V2G-ready system and equipment. These impacts exist regardless of how – or even if – V2G is performed. Thus, the study functions as a first step towards better assessing the environmental impact of V2G by identifying the added burdens of the equipment that any V2G implementation should overcome, laying the groundwork for future studies.

4.07.A.T-03 Assessing the Evolution of Environmental Impacts in Vehicle Gliders
Felipe Bitencourt de Oliveira, Chalmers University of Technology; Anders Nordelöf, Chalmers University of Technology; Maria Bernander, Volvo Car Corporation; Björn Sandén, Chalmers University of Technology.

Advances in automotive technology, particularly the shift towards electrification, have highlighted the necessity of understanding the full range of environmental impacts associated not only with vehicle operation but also with manufacturing processes. While much focus has been placed on the impacts of powertrain components, there is a gap in understanding the broader environmental burdens posed by other vehicle systems, especially as newer designs incorporate lightweight materials and advanced electronics.

This study employs an attributional life cycle assessment (LCA) to quantify the environmental impacts of vehicle gliders – vehicles without their powertrain – from model years 2012, 2016, 2020, and 2024. Data on material composition is extracted from the International Material Data System (IMDS), an industry-wide database containing detailed information on substances present in automotive components and supplemented with Volvo Cars' internal Vehicle Construction Database. Several environmental impact categories using midpoint characterization methods are evaluated. Additionally, a temporal analysis is conducted to investigate how changes in vehicle design and material use over time influence the overall environmental burden.

The analysis is expected to reveal that newer vehicle gliders incorporate a higher number of lightweight materials and electronic components, driven by safety and environmental regulations, as well as consumer demand for enhanced comfort, digital connectivity, and automation. These trends are likely to have implications for various environmental impact categories. For instance, global warming potential and resource depletion could be influenced by the glider's weight and an increased presence of electronic components, as these are generally associated with energy and resource-intensive manufacturing processes. Additionally, toxicity results might vary in newer gliders due to the implementation of stricter regulations regarding hazardous materials.

The findings from this study aim to provide critical data that can inform manufacturers and policymakers, helping to address the challenges in developing better strategies for material use and recycling. By highlighting the evolving environmental burdens associated with vehicle gliders, this research supports efforts to make automotive design and production more environmentally friendly.

4.07.A.T-04 Addressing Logistics Optimisation in Life Cycle Assessment
Simon Alexander Saxegård, Norwegian Institute for Sustainability Research ; Regina Skattenborg, Norwegian Institute for Sustainability Research.

Introduction: Transport and logistics are often optimized with respect to reducing environmental impacts. Parameters often addressed for environmental logistics optimization are load capacity utilization, vehicle size optimization, driving patterns, fuel sources, logistics planning etc. Currently most life cycle assessment (LCA) databases provide static transport activities, which are defined for generic load capacity, EURO class and vehicle sizes. Adaptive transport and logistic tools exist, but these are often only including a well to wheel scope and are not eligible as LCA results nor environmental declarations. It is therefore a mismatch between the optimization efforts which the transport and logistic industry apply and what LCA practitioners can effectively assess. In addition, emissions of microplastics (MP's) caused by road and tyre wear are commonly not an integrated part of transport LCA's despite that it is a prominent source for a well-known environmental problem.

Method: In this study common analytical frameworks used for developing well to wheel emission profiles are adapted to also include infrastructure such as vehicle and road production, maintenance, and end-of-life scenarios. The life cycle inventory is collected per km driven and recalculated per ton kilometer based on the vehicle cargo load. Commonly assessed impact categories are used for the LCA.

Results: The results demonstrate an exponential impact growth from 100% up to 450% impact increase between 100 and 12.5% capacity utilization factor for several commonly included environmental impact categories the lower the capacity utilization is. The results also show contrary to common LCA results that under certain conditions smaller lorries are recommended for minimizing transport related emissions.

Conclusion: The findings form this study demonstrate that efforts towards optimizing capacity utilization alone is very influential to the environmental impacts of a products logistics. Similarly, infrastructure is a significant environmental contributor to the net burden of transport. The preliminary assessment shows significant variation in impact across a broad range of impact categories. It is therefore necessary to enable LCA practitioners to assess the implications of transport and logistic optimization efforts to be in tune with the current doctrine of the industry.

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4.07.A.T-05 Next Level Lightweight Production: Environmental assessment of lightweight components and alternative drive technologies in the commercial vehicle sector
Eva Sophie Jurgeleit, University of Applied Science Bonn-Rhein-Sieg; Maria Lozano, University of Applied Science Bonn-Rhein-Sieg; Stefanie Meilinger, University of Applied Science Bonn-Rhein-Sieg; André Stieglitz, ZF Friedrichshafen AG.

In the transportation sector, decarbonization is necessary to make a significant contribution to achieve European climate targets by 2050. Around three-quarters of the volume of goods transported within Europe is predominantly done by heavy-duty road transport. This results in significant greenhouse gas emissions as commercial vehicles continue to run on fossil fuels. The central question is how emissions in this sector can be reduced and how non-renewable resources can be conserved. The collaborative project “Next Level Lightweight Production” (NeLiPro), funded by the German Federal Ministry for Economic Affairs and Climate Protection (BMWK), addressees this question by investigating the environmental impact of lightweight components used in freight transportation.

Our contribution examines the environmental impact effects of weight-reduced chassis components in commercial heavy-duty vehicles over their entire lifecycle. An innovative and hybrid lightweight structure was accompanied in the early stages of product and process development. The methodology of life cycle assessment has been used to identify environmentally friendly optimization measures in product design and in the process chain. In addition, various disposal and recycling scenarios for the components have been examined and evaluated to recover valuable resources from these components and use them elsewhere, such as in cement plants. The results and sensitivity analyses supports strategic decisions regarding potential series introduction. In comparison, the environmental impacts of a current metallic reference structure have been evaluated over its entire life cycle. The study shows that the use of lightweight components in heavy commercial vehicles reduces fossil fuel consumption during the use phase (Fuel Reduction Value). However, the amount of greenhouse gas emissions depends on the type of engine used and the route profile. Here we used a newly developed simulation model to calculate fuel consumption and associated CO2 emissions for different route profiles, masses and drive technologies. For a conventional diesel engine, the model was compared to the results of the VECTO tool from the European Commission. Route profiles for urban, long-haul, and regional were taken from VECTO. The model is based on realistic vehicle parameters considering two different drive technologies: A conventional diesel engine as well as a hydrogen burner.

4.07.B.T-06 Using Hydrogen in Long-Haul Heavy-Duty Trucks: A Life Cycle Assessment Approach

Jorge Enrique Velandia Vargas, Chalmers; Selma Brynolf, Chalmers; Maria Grahn, Chalmers; Felipe Rodriguez, Colorado State University; David Blekhman, California State University.

The purpose of this study is to estimate the environmental impacts of using hydrogen on FCTs and ICETs on the Swedish context, via life cycle assessment (LCA). We considered green and blue hydrogen for production, and one additional pathway of SMR using biomethane as feedstock, which has the potential to result in negative emissions when CCS is included. We explored onsite production at the hydrogen refuelling station (HRS), which eliminates the need for transportation and at a central plant, which enable the gains of economies of scale. For the central production cases, we evaluated four transmission and distribution pathways intended to represent Swedish conditions and two cases of production abroad: in Chile due to its low-cost electricity (IRENA, 2022a) and Norway due to the large natural gas (NG) reserves. Finally, this study aimed to perform a broad sensitivity analysis for parameters that are expected to have a significant environmental contribution throughout the entire life-cycle stages.

We apply the LCA methodology which quantifies the impacts from a cradle-to-grave perspective. In order to determine the final product system to be evaluated we firstly selected the pathways of transmission and distribution of hydrogen. We ended up including two cases of hydrogen production abroad which is then imported to Sweden, on liquid state, via tanker. Moreover, for FCT and ICET modelling we constructed different vehicle topologies based on own assumptions and feedback by automotive industry experts.

It is important to highlight that our product system includes the creation of the so-called Gothenburg hydrogen hub; a logistic hub at the city gates where hydrogen is stored at large scale to guarantee supply for the future hydrogen economy. The time scope for our analysis is the decade between 2020 and 2030. An attributional approach was applied. Results will be presented for global warming potential, mineral resource scarcity, human toxicity, and energy demand. As recent research has raised questions around the GHG potential of hydrogen, we included the potential leaks throughout the entire life cycle. A graphic depiction of the system boundaries is included in Figure 1.

4.07.B.T-07 EU Shipping Fleet Decarbonization: Well-to-wake Assessment Model

Fayas Malik Kanchiralla, Chalmers; Jette Krause, European Commission - Joint Research Centre; Georgios Fontaras, European Commission - Joint Research Centre; Lorenzo Maineri, European Commission - Joint Research Centre; Adam Bellos, European Commission - Joint Research Centre.

Maritime shipping is a major contributor to global CO2, SO2, and NOx emissions due to its reliance on fossil fuels. The shipping industry has been making efforts towards an energy transition, as evidenced by the significant increase in orders for ships powered by alternative fuels. It is important to develop climate-friendly energy transition strategies that capture political decision impacts, development in the technological system, and transport demand for shipping using a bottom-up approach.

Energy system models often consider the possibility of achieving a climate target but ignore other environmental impacts. Integrating them with life-cycle assessment (LCA) models will allow the evaluation of other environmental impacts, and help understanding the trade-offs of different strategies. However, the coupling of the LCA models with energy system modeling is challenging as both methods are data-intensive and complex. Another challenge is that the LCA approach provides static snapshots and thus needs to be extended to include prospective scenarios.

This study aims to provide a perspective on future Well-to-wake greenhouse gas emissions of low-carbon solutions in the context of the EU shipping fleet by integrating prospective LCA into energy modeling. For the preliminary calculation, well-to-wake energy consumption, and greenhouse gas emissions, are calculated based on maritime fleet energy consumption projections within a clean energy technology scenario, stemming from an energy system model, and related life cycle assessments performed for the shipping sector. The calculation is performed separately for domestic shipping, intra-EU, and international shipping. According to the analysis, well-to-wake GHG emissions for both the intra-EU and international would rise until 2030 and then begin to decline. However, the emissions for domestic shipping will begin to decline from 2025. Achieving a net-zero or 80% reduction target by 2050 would be difficult to achieve for the shipping sector even if the reliance on fossil fuels is reduced. The well-to-wake energy consumption shows that there would significant increase in the demand for electricity and biomass energy to cater to the need for shipping decarbonization.

4.07.B.T-08 Life Cycle Inventories for Aviation: Background Data, Shortcomings, and Improvements

Joana Albano, German Aerospace Center (DLR); Antonia Rahn, German Aerospace Center (DLR); Jens Bachmann, German Aerospace Center (DLR).

In aviation, Life Cycle Inventory (LCI) data representativeness and completeness are usually hindered by confidentiality by aircraft manufacturers, maintenance providers or operators, leading to significant gaps. Aiming to improve life cycle data coverage, a use-case on aircraft Maintenance, Repair, and Overhaul (MRO) foreground inventory integration into background databases is presented, modeling various maintenance tasks and their frequencies based on recent aircraft maintenance Life Cycle Assessment (LCA) studies [1]. The in-depth LCI covers both airframe and engine maintenance, including upstream activities such as energy, materials, and resources usage for different flight distances, and is to be connected to datasets for aircraft and kerosene production, and airport infrastructure through a common functional unit. The aircraft's life cycle is simulated using DLR's LYFE tool for discrete-event simulation [2], based on flight schedules and maintenance intervals. Since aircraft and engine have distinct operational lifetimes and maintenance requirements, MRO activities should be split into engine and airframe (structure and components). In addition, the occurrence of maintenance activities for each flight distance changes, e.g. aircraft operating in very short- or short-range networks exhibit higher number of flight cycles due to shorter distances and more frequent flights, whereas long- and very long-range routes present higher flight hours due to longer flights per cycle. The level of data aggregation depends on the intended purpose of the study and the target audience. MRO and industry experts may require more detailed inventories, whereas the aggregation level is higher for LCI background databases. The high flexibility of our aircraft life cycle simulation tool allows for calculations of maintenance efforts for different flight distances. Our findings contribute to the advancement of LCA in aviation by providing insights into improving data accuracy and completeness.

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4.07.B.T-09 Life Cycle CO2e Intensity of Commercial Aviation with Sustainable Aviation Fuels using Actual Flight Data
Aron Bell, Trinity College Dublin; Liam Anthony Mannion, Trinity College Dublin; Mark Kelly, Trinity College Dublin; Mohammad Reza Ghaani, Trinity College Dublin; Stephen Dooley, Trinity College Dublin.

Background and Purpose: Aviation faces a significant challenge in achieving targets of net-zero in 2050. Sustainable aviation fuel (SAF) is the primary emission reduction mechanism in the short/medium-term. In this study, LCA is performed to account i) the total carbon dioxide equivalent (CO2e) embodied in specific SAF (derived from used cooking oil) and ii) the well-to-wake CO2e emitted during commercial flights, considering the specific fuel and aircraft technology utilised. The CO2e intensity of flights is expressed in the industry standard reporting metrics of gCO2e per revenue-passenger-kilometre (gCO2e/RPK) and gCO2e per revenue-tonne-kilometre (gCO2e/RTK).

Methods: This LCA is performed from first principles, allowing full control over the inputs and methodology employed. Existing LCA tools are found to restrict the key pillars of specificity, granularity, and transparency in this study. Actual aircraft data is provided by Ryanair, which informs the mass of fuel used during the flight and the number of passengers onboard. The CO2e emissions from non-fuel related activity such as airport operations are also included.
Results: The CO2e intensity of the SAF is calculated to be 12.2, 12.6, and 17.4 gCO2e/MJ depending on the supply chain of the used cooking oil. These represent 81-87% reductions compared to the fossil aviation fuel baseline. The well-to-wake CO2e intensity of a commercial flight from Amsterdam to Dublin is shown to be 117.8 gCO2e/RPK when operated by a Boeing 737-800 with industry average load factor and fossil aviation fuel. This CO2e intensity can be reduced by 18% when the load factor is increased to 100%, and by a further 20% when the aircraft is replaced by the new generation Boeing 737 Max 8. Finally, the use of the modelled SAF at the maximum 50% blend fraction, with a Max 8 and 100% load factor yields an intensity of 43.8 gCO2e/RPK. A Monte Carlo uncertainty analysis shows that the CO2e intensity is uncertain to approximately ±12% due to uncertainties in input data and variabilities in the scenario specifics.
Conclusions: SAF is seen to provide the largest opportunity for CO2e reductions from commercial aviation. Specificity and rigorous supply chain analysis are crucial for the accurate determination of the life cycle CO2e that is embodied in SAF and emitted during commercial aviation. Access to transparent and reliable data is seen as the major challenge to reducing uncertainty in the LCA of SAF and flight operations.

4.07.B.T-10 Life Cycle Assessment of CO2 Capture from Lime Production and its Conversion into E-methane for its Utilisation as Fuel in a Ship
Jordy Motte, Ghent University; Erasmo Cadena, Ghent University; Jim Gripekoven, ENGIE Laborelec; Koen Vlaeminck, ENGIE; Friso De Clercq, Carmeuse; Jo Dewulf, Ghent University.

CO2 capture and utilisation (CCU) technologies have great potential to mitigate climate change. In the Columbus project, an example of a CCU initiative located in Belgium, CO2 is captured from lime production and converted into E-methane. This synthetic fuel can be a more environmentally friendly alternative to heavy fuel oil, currently the conventional fuel for ships. Moreover, the Columbus process is mainly powered by renewable electricity. According to the consulted literature, no life cycle assessment (LCA) is available on the CO2 capture from lime production and its subsequent conversion into E-methane. This paper aims to assess the environmental impacts of E-methane production via the Columbus process and its utilisation in a ship benchmarked to conventional fuel production (reference) through LCA.

A cradle-to-grave LCA was conducted, meaning that the distribution and utilisation of E-methane was included in the scope. A basket-of-products approach was used to also consider the co-products (i.e., oxygen, lime and heat) obtained from the Columbus process in the assessment. The functional unit was defined as 1 km transport via ship and the conventional production of the co-products delivered by the Columbus process. Several indicators were selected for the LCA, namely climate change, fossil resource use, mineral and metal use, particulate matter formation, human toxicity and water use. Finally, a scenario analysis was performed assuming a fully renewable electricity mix.

The results show that E-methane production and utilisation in a ship leads to a 91% and 85% reduction of greenhouse gas emissions and particulate matter emissions, respectively, compared to the reference. In contrast, replacing heavy fuel oil by E-methane results in an increase of water, minerals and metals consumption. Water use increases with 386%; minerals and metal resource use even rises with 1931%. Nevertheless, a shift to a fully renewable electricity mix significantly decreases the impacts of the Columbus process on the environment. For example, fossil resource use would drop with 87%. The electrolysis has the largest share to the results for most indicators due to the significant amount of electricity required for this production step. Finally, future research should focus on the social aspects and the economic feasibility of the Columbus process.

4.07.P - Better Data and Modelling for Sustainable Transport

4.07.P-Tu067 Life Cycle Assessment of Electric Ferries Based on Various Lithium-ion Battery Technologies

Fayas Malik Kanchiralla, Chalmers University of Technology; Selma Brynolf, Chalmers University of Technology; Emma Grunditz, Chalmers University of Technology; Evelina Wikner, Chalmers University of Technology; Anders Nordelöf, Chalmers University of Technology.

The electrification of passenger ferries is of interest as they often operate on shorter routes and can take advantage of opportunity charging. It is a way to decrease dependence on fossil fuels and reduce emission of greenhouse gases and air pollutants. However, different types of battery chemistries have different performance characteristics, and the ship's performance regarding the sailing range, charging strategy, operational energy, and lifetime varies with the use of different Li-ion battery technologies. Also, the batteries are material- and energy-intensive to produce. In this study, a life cycle assessment is performed for a battery electric vessel, comparing two different Li-ion batteries: graphite negative electrode and LFP or NMC positive electrode. The global warming potential of two Li-ion battery technologies is compared along with the original diesel option. Irrespective of the battery chemistry, the battery electric ferries have significantly less climate impact than the diesel alternative. Although the differences between battery technologies are relatively small, the analysis shows that LFP batteries offer a good solution for the case study ferry. Lesser emissions during manufacturing and a lower number of replacements make LFP more appropriate than NMC despite that the heavier LFP batteries increase the operational energy use. However, these assumptions are based on battery pack sizes considering fast charging and opportunity charging. A modification of the charging strategy would change the required pack sizes, necessitating a furhter investigation for such a case.

4.07.P-Tu068 Recycling of Organic Residues and CO2 Into Fuels (reTURN) - Carbon Footprint Modell of a Novel Fuel Production Route Power-and-Biogas-to-Liquid (PBtL)

Felix Hoenighausen, University of Applied Science Bonn-Rhein-Sieg; Andreas Waibel, CAPHENIA GmbH; Eva Sophie Jurgeleit, University of Applied Science Bonn-Rhein-Sieg; Stefanie Meilinger, University of Applied Science Bonn-Rhein-Sieg.

Sustainable Aviation Fuels (SAF) are set to have a pivotal role to decarbonize the aviation industry. Emerging Power-to-X (PtX) technologies hold the promise of producing these fuels sustainably. Assessing the sustainability and carbon footprint of such processes requires comprehensive Life Cycle Assessments (LCA).

In the collaborative project reTURN, funded by the German Ministry for Economic Affairs and Climate Action, CAPHENIA GmbH is developing a technology for the production of synthetic fuels called Power-and-Biogas-to-Liquid (PBtL). This PtX approach uses biogas, utilizing both biogenic methane and biogenic carbon dioxide, alongside water and electricity. These feedstocks are synthetized in a so-called Plasma-Boudouard-Reactor to produce syngas which is later transformed via Fischer-Tropsch (FT) synthesis to various fuels like kerosene, diesel, or petrol. PBtL represents a hybrid PtX technology, leveraging both electricity and biomass as primary inputs.

This study presents a newly developed prospective carbon footprint model capable of calculating the GHG emissions associated with SAF production across the entire lifecycle, considering variable parameters such as location, electricity sources, biogas composition, allocation factors for co-products etc. A comparative analysis with different feedstock compositions within PBtL and alternative production routes like Power-to-Liquid (PtL) or Biomass-to-Liquid (BtL) is carried out. Additionally, a separate assessment of the built infrastructure has been conducted to evaluate its GHG emissions relative to the GHG emissions of the production and use phase of the synthetic fuels. Finally, an uncertainty analysis allows to make statements about the precision of the results.

Preliminary findings indicate a reduction in greenhouse gas emissions compared to the fossil fuel benchmark outlined in the Renewable Energy Directive III (RED III), aligning with mandated GHG emission savings for biofuels. Furthermore, initial assessments suggest that the GHG emissions associated with the infrastructure may be offset within a few months of the proposed operational lifespan of the production plant, indicating a potential for a relatively fast GHG amortization.

These findings advance the field by providing a carbon footprint model that can be applied to optimize and validate the sustainability of various synthetic fuel production pathways.

4.07.P-Tu069 Review of Methodological Challenges in Life Cycle Assessment of Heavy Duty Road Transport

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Although most product systems involve transport, generic data is frequently used when modelling transportation in life cycle assessment (LCA). Transport is typically considered as part of the background system, and access to specific data is in many cases limited. The generic data include a large set of underlying assumptions, and there is a need for increased knowledge about the significance of these assumptions.

The aim of this study was to identify the most relevant methodological aspects in LCA related to heavy goods transport, and to evaluate their importance. This was done by performing a semi-structured literature review and to test the importance of these aspects by performing a case study of the transport of bulk masses excavated from a building site. The case study was chosen due to increased targets to reuse excavated masses to improve circular economy in the building sector. Reuse of masses can potentially lead to a substantial increase in transportation and temporary storage needs.

The relevant methodological aspects identified were: transport distance, fuel type and capacity utilization, including load factor and return trip. Based on the findings in the case study, a set of recommendations for the modelling of heavy-duty road transport was proposed to advice LCA practitioners about how to develop more specific transport models.

4.07.P-Tu070 The Propagation of Uncertainty in the Life Cycle Assessment of Sustainable Aviation Fuel and Commercial Flights

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Background and Purpose: Sustainable aviation fuel (SAF) is generally accepted to be the primary method to reduce CO2e emissions from aviation in the short- to medium-term. Life cycle assessment (LCA) is required to account the total CO2e embodied in SAF. All LCAs have uncertainty due to the quality of the input data and variability in scenario specifics, however uncertainty is not always reported. This study quantifies the uncertainty associated with life cycle CO2e intensities of specific SAF and commercial flights that use SAF.

Methods: This methodology employs a Monte Carlo uncertainty propagation, involving the simultaneous perturbation of each input parameter. An uncertainty range and distribution type are defined for each parameter used in the LCA calculation, informed by SAF certification requirements, literature data and scenario assumptions. The Monte Carlo simulation is performed for 20,000 iterations, randomly sampling each input parameter from the uncertainty range and distribution type assigned to it. This is performed for every stage of the SAF life cycle; the results of which also inform the uncertainty analysis on the CO2e intensity of specific commercial flights, using actual flight data provided by Ryanair.

Results: For a SAF with a life cycle CO2e intensity of 12.2 gCO2e/MJ, the consideration of input parameter uncertainty results in a 95% confidence interval range of 10.9 – 13.5 gCO2e/MJ. This uncertainty is important for airlines who report emission savings from the use of SAF and highlights that default LCA values may not be sufficient. For the CO2e intensity of specific flights that use SAF (where the nominal value is 54.3 gCO2e per revenue-passenger-kilometre), the uncertainty of the SAF CO2e intensity and the variability in the mass of fuel used during a flight and the number of passengers onboard, leads to a large range of 48.1 – 60.9 gCO2e per revenue-passenger-kilometre.

Conclusions: Uncertainties arising from input values and scenario assumptions require transparency to appreciate the particulars of the calculation and to evaluate the potential inaccuracy of the results presented. Specific, accurate, and verifiable data is required to increase confidence in the life cycle assessment of CO2e emissions associated with specific SAF and commercial aviation.

4.07.P-Tu071 The Importance of Reliable Secondary Life Cycle Data in Databases – The Example of Nickel

Pablo Rodríguez Domínguez, Nickel Institute.

Civil society, regulators and authorities, downstream and end users, trade platforms, investors, and academia are all showing a growing interest in the sustainability performance of a company and its products throughout the entire life cycle. Life cycle data is increasingly deciding on access to markets, license to operate and access to finance for nickel producers. Nickel is a metal of specific interest, as it plays a critical role in mitigating climate change by e.g., green mobility or the energy transition where nickel plays a role due its extensive use in EV battery technologies and low carbon power generation.

In this review, Nickel Institute provides an analysis of historical, updated and recent life cycle data for the production of different nickel products. Special emphasis is put on the development of methodologies and modelling approaches and how they affected the results. An insight will be given into ongoing work of the Nickel Institute to further harmonize the data collection, computation and interpretation of LCA results in nickel production.

Different methods could result in varying data requirements for member companies, different interpretations of those data and – in consequence – deviating results. Ensuring scientifically sound methods, coherent data requirements and consistent data interpretation is the path to a ‘level playing field’ for nickel producers.

4.07.P-Tu072 LCA Model for Roads at District Scale

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Introduction
In 2021, urban areas accounted for 75% of global energy use and produced 70% of CO2 emissions. Cities are thus critical in the energy transition, focusing on both mitigation and adaptation.

Urban artificialization is notable in public spaces. For example, in Paris in 2000, 60% of public space was for cars. However, private car use in cities is declining in favor of buses and rail. This calls for evolving roads, currently 80% dedicated to cars.

At neighborhood scale, infrastructure impacts are often underestimated. The goal is to model the impacts of road construction and maintenance. This model evaluates the sensitivity of various indicators to different processes, identifying key data for roads. The study uses French road design best practices through Brightway.

Methods
A standard bitumen road structure was selected, supporting high traffic. The processes include refinery, quarry, asphalt plant operations, energy systems, construction machinery, and transportation. The model uses EcoInvent data, with additional data from Jullien et al (2006).

A Monte Carlo analysis and sensitivity analysis were conducted for indicators like Cumulative Energy Demand and global warming potential.

Results
For the construction phase, the model calculates a CED of 20 TJ and a GWP of 1600 t CO2 eq., with aggregate consumption at 21,000 t for 30,000m² road. Maintenance phase impacts, using 40% recycled aggregates, are roughly half of the construction phase.

Comparisons with specialized road LCA tools show similar results, with a factor of 2 difference in CED and GWP between them and our model. Aggregate consumption remains comparable, but a factor of 4 difference is noted with Pleiades for CED.

Bitumen production is the most sensitive parameter affecting both CED and GWP. Comparing road impacts to a neighborhood LCA case study, roads contribute 1% to CED and 2% to climate change impacts (GWP100).

Conclusions
A road LCA model using EcoInvent data and specialized literature adaptations was developed. The model, though limited to thick bituminous structures, represents common French construction techniques. Results highlight the relatively low impact of roads within neighborhoods, suggesting a focus on mobility impacts at the

district level. Bitumen production is a significant contributor to CED and GWP impacts. Roads could support green belts and networks in cities, reducing biodiversity impacts and improving urban living environments.

4.07.P-Tu073 Methodological Challenges in Aviation Life Cycle Assessment

Elisa Accorsi, Politecnico di Torino; Isabella Bianco, Politecnico di Torino; Gian Andrea Blengini, Politecnico di Torino.

The aviation sector is increasingly aware of the environmental impacts associated with air transportation. Recent initiatives by the European Union and Europe's aeronautics industry aim to enhance the environmental performance of aviation, particularly in terms of climate change indicators. Internationally, the International Civil Aviation Organization (ICAO) has issued a Climate Change Adaptation Synthesis and provided guidance on climate change risk assessment and adaptation planning. Within the EU, the Climate Adaptation Strategy commits to integrating climate resilience considerations across all relevant policy domains [1].

Given this context, there is a growing emphasis on conducting through analyses of the aviation sector's environmental impact using specific methodologies. The primary objective of this report is to contribute to the development of a comprehensive knowledge base on environmental aspects, serving as a reference for new methodologies to analyse aircrafts and their components through Life Cycle Assessment (LCA).

While some LCA studies have explored sustainable aviation alternatives, as exemplified by Pimchanok et al. [2], there remains a notable scarcity of literature focusing on Life Cycle Inventory and methodologies related to the manufacturing of entire aircraft or specific components. For instance, R. Veeramanikandan et al. [3] delve into the composition of turbine blades.

As a contribution to overcome the challenges in accessing inventory data, the paper proposes tailored methodologies that blend top-down and bottom-up approaches. This study lays the foundation for developing a new approach applicable to entire aircrafts or their assemblies. The results contribute to creating a comprehensive starting point framework for building more and more accurate inventories.

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4.08 - Modelling of Waste Management

4.08.T-01 Life Cycle Assessment Allocations for Circular Economy in Construction Sector: Methodological Discussion

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Construction sector is responsible of about 69% of waste production in France. Therefore, Circular Economy (CE) is being promoted by laws, and urban planners in this sector, to reinject these materials into production, by recycling, reusing, renovating or to review the needs of consumption all over the life cycle of the operation.

CE is often related to sustainable development, as this concept must help lower our impact on the environment. But circularity does not imply positive impacts on the environment, and studies on life cycle assessment and circular economy are increasing in that way.

These studies reveal some limits of life cycle assessment (LCA) for construction sector, such as its difficulties to model interactions between different life cycles. By recycling, reusing etc. some flows are exchanged between life cycles of different operations, such as deconstruction operations, and construction operations. To model those interactions, allocation factors allow to share out between operations the impacts related to those flows transfer. There is a lot of allocation modes used for circular economy. The adding of different CE allocations makes the comparison between LCA studies even more difficult, especially on the interpretation of results. This work first focused on identify the allocation methods used nowadays in LCA for CE in construction sector, by looking at literature, reviews on allocation for CE, applied studies for CE in built area, etc. Then a discussion on the benefits and drawbacks of each method according to different criteria is made, by analyzing the consistency of the LCA (no double counting), the applicability of the method (need for data, ease of understanding), induced undesirable effects (rebound effect, biogenic carbon) and the relevant circular economy levers to be associated with. The aim of this research is to provide a method to choose the right allocation type according to the LCA study that is being made.

4.08.T-02 An Overall System Perspective on Food (Processing) Residues in Life Cycle Inventories

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Food waste and residues are key in reducing environmental impacts of food consumption, sparking political interest. Various initiatives aim to minimize waste and optimize use, though many overlook upstream environmental costs. Interconnected sectors like energy and materials are often neglected, impacting Life Cycle Assessment results.

This summary of Life Cycle Assessment studies explores disposal, use, and valorisation of food processing residues, emphasizing the importance of considering cut-off approaches and the polluter-pays-principle.

For instance, the market for used cooking oil and substrates in biogas plants are examined. Different pathways for utilizing food processing residues include upgrading for food, fodder, fertilizer, biomaterials, biochemicals, and energy production. However, not all ideas are environmentally friendly due to market dynamics and pricing of waste substrates. An example involving whey as pig feed highlights the ecological implications of different processing scenarios. While one scenario is more environmentally favourable, another involving higher processing levels performs worse due to increased energy consumption and waste disposal.

Life Cycle Assessment of food residues often raise allocation questions, advocating for the consistent application of the polluter-pays-principle. Incomplete assessments may result from cut-off approaches, emphasizing the need to consider impacts of upgrading and valorisation efforts. Defining clear scenarios for comparison is crucial, although not all pathways may be considered. Life Cycle Assessment results can influence markets, potentially leading to higher impacts if prices increase due to environmental performance. This underscores the importance of evaluating both sides of the coin and considering the broader implications of waste management and resource utilization.

4.08.T-03 Comparison of Different End-of-Life Modelling Approaches for an Environmental Life Cycle Assessment of Agrivoltaic Systems in Austria

Theresa Krexner, BOKU University; Alexander Bauer, BOKU University; Iris Kral, BOKU University.

Agrivoltaics (APV), i.e., the parallel use of agricultural land for food/feed and electricity production using photovoltaic (PV) modules, is currently a highly relevant research topic due to its potential to increase land use efficiency. In the authors' previous study, environmental impacts of two APV systems were assessed using the Life Cycle Assessment method and further compared with selected mono-uses of agricultural land, either agriculture or electricity production using PV modules. For a fair comparison a system expansion approach was used to evaluate both outputs, agricultural goods and electricity. So far, system boundaries were only set cradle-to-gate. In order to conduct a full LCA, the focus is now on the end-of-life (EoL) phase and its combination with previous study results. Goal of the proposed study is to compare selected EoL approaches applied to a multi-output product system, for which a system expansion approach (cradle-to-gate) has already been applied. In particular, a stilted (S-) and a vertical bifacial (VB-)APV system are evaluated. As EoL modelling approaches, cut-off approach with allocation by classification (CO), open-loop with closed-loop recycling procedure with expanded system boundaries (OL) and the Circular Footprint Formula (CFF) are assessed. Initially these approaches will be applied to the steel and aluminium mounting structure; in a next step to the whole APV system (also including the module). For recycling input and rate European averages are used. Functional unit is set to one dismantled APV plant after 30 years of use. As software openLCA v2.1.1 with ecoinvent database v3.8 and ReCiPe 2016 Midpoint (H) impact assessment method is used. Highest environmental impacts in the climate change impact category when applying all EoL approaches to the mounting structure are found for the CO approach. Impact reductions of 23% (S-APV) and 20% (VB-APV) are identified with OL, 40% (S-APV) and 35% (VB-APV) with CFF. The study reveals notable variations in the results due to the three evaluated EoL methods. The CO approach, though easy in handling, lacks recycling incentives. 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.

4.08.T-04 Allocation of Emissions from Waste Incineration with Energy Recovery in Life Cycle Assessments of the Built Environment

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Background and purpose

Waste incinerated with energy recovery creates an allocation problem in Life Cycle Assessment (LCA), where environmental impacts must be allocated between the waste treatment and energy production. Choice of allocation method can alter the incentives given to choose waste treatment options, energy systems, and energy efficiency measures in construction projects. There is a need to improve our understanding of how allocation methods affect LCAs of the built environment.

Methods

We reviewed allocation methods for waste-to-energy used in LCAs of buildings and neighbourhoods. Incentives given through an LCA during planning of construction projects was quantitatively evaluated across methods. We considered both a waste producer perspective aiming to ensure environmentally beneficial waste treatment and an energy planner perspective designing sustainable energy systems. Incentives given with varying allocation was compared to results from system expansion.

Results

The literature review showed that a range of allocation methods exists, including simple methods such as binary and equal split allocation and more complex methods such as based on economic parameters.

The emission intensity of waste-to-energy based district heating is heavily affected by chosen allocation method. Typically, allocating all environmental impacts to the life cycle that generates waste will make district heating increasingly environmentally competitive if decisions are LCA based. Increased allocation to energy may instead incentivize separate decentralized production through heat pumps, whilst also increasing incentives for energy efficiency measures in buildings.

Fossil plastic waste generated in a construction project is less sensitive to changes in allocation, with incentives typically given to recycling over energy recovery if a share of impacts is allocated to the waste producer.

Conclusions

For incineration of mixed waste, non-recyclable waste or hazardous waste, energy recovery for district heat should not be disincentivized. This can be ensured by allocating all emissions to the waste producer. Increased allocation to energy production should only be considered for incineration of pure waste fractions of high-quality that would otherwise be recycled or reused, or for the case of plastics, landfilled without producing other environmental impacts.

The work was done as part of the FME ZEN project (funded by the Research Council of Norway, project number 257660).

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4.08.P-Mo051 Evaluating Allocation Approaches in Comparative LCA for Reusing Building Elements

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Background and Purpose

Environmental impact allocation between Life Cycle Assessment (LCA) modules and subsequent life cycles presents significant challenges, especially when reusing building components rather than recycling. This challenge is intensified in comparative LCA for decision-making, where different allocation approaches, such as cut-off and others, can yield varying and sometimes contradictory results. Additionally, allocating impacts from end-of-life processes, such as deconstruction versus demolition, raises questions about whether some impacts should be allocated to the next life cycle due to the nature of deconstruction, which is akin to producing a product for reuse. The relevant European standards EN15804 and EN15978 provide guidelines for impact allocation in reuse scenarios but require interpretation due to the emerging nature of reuse strategies in the building sector, particularly for structural concrete elements. This study aims to apply possible allocation approaches in LCA of a real-life reuse project and discuss their impact on decision-making and sustainability.

Methods
This study is grounded in a real-life field experiment involving the reuse of building elements. Data collection for the LCA was conducted through interviews, dialogues, observations, document analysis, and workshops. We applied the end-of-life allocation approach (0:100) and the BPX 50/50 adapted approach in parallel with the cut-off approach. These approaches are less theoretical and more applicable than the 50:50 approach, which requires an exact number of use cycles, whereas the chosen approaches only need to determine if the use cycle under study is the last or not. The allocation of deconstruction burdens to the element to be reused is discussed based on practical limitations and ethical considerations.

Results
Our findings reveal that the choice of allocation approach significantly influences LCA results, particularly when different numbers of use cycles are assumed. Other assumptions about the number of reuse cycles led to varying and sometimes contradictory LCA outcomes.

Conclusions
The study highlights the critical impact of allocation approaches on LCA results in reuse scenarios for building components. More precise guidelines are needed to improve consistency and accuracy, supporting better decision-making for sustainable building practices.

4.08.P-Mo052 How are Methodological Choices Affecting the Results of Life Cycle Assessment Studies on Polyethylene Terephthalate Recycling?

Maria Ciotti, Chalmers University of Technology; Mathias Janssen, Chalmers University of Technology.

In 2019, the global production of plastic waste hit 353 million tonnes, requiring significant improvement in waste management practices and reduction strategies. Nevertheless, in Europe only 12% of plastic waste is recycled. Among common plastic polymers, Polyethylene Terephthalate (PET) is the most recycled. To promote its recycling, the European Union has mandated a minimum threshold of 25% recycled PET content in beverage bottles by 2025, reaching 30% by 2030. Since Life Cycle Assessment (LCA) has been used for comparing the environmental impact of different waste management solutions, we decided to conduct a literature review to determine the actual status of LCA studies on PET's end-of-life.

56 pertinent articles were identified with literature database searches and snowball sampling techniques. These articles were analyzed with an emphasis on their goal and scope definition. Given PET's high recycling rate, particular attention was dedicated to understanding the extent to which allocation choices influence research outcomes and subsequently the use of recycled materials in production processes.

Preliminary results show that a consensus regarding the most sustainable PET waste management strategy is difficult to identify in the literature, given the different methodological approaches adopted in LCA modeling that complicate meaningful comparisons. Mechanical recycling, landfilling, and incineration with energy recovery are mostly in focus, reflecting their importance in the present market. Recent research has also investigated chemical and enzymatic recycling solutions. However, these techniques are not yet competitive in terms of greenhouse gas emissions and energy consumption, due to their lower technological readiness levels and scales. It was observed that significant attention is required when modeling their scaling-up and system's foreground and background.

This literature review also attempts to discern potential correlations between methodological choices and ranking of waste management strategy. Based on expected results, recommendations for conducting LCAs on PET end-of-life could be defined. A transparent definition of methodological choices is indeed fundamental to guarantee a full understanding of the study findings and facilitates meaningful comparisons.

4.08.P-Mo053 Life Cycle Assessment of Precise Sorting and Recycling of Lightweight Packaging

Leon Deterding, Institute for Industrial Ecology; Tobias Viere, Institute for Industrial Ecology; Jörg Woidasky, Institute for Industrial Ecology; Claus Lang-Koetz, Institute for Industrial Ecology.

Background and Purpose
Plastic production in the EU was responsible for the emission of 208 million tons of CO2-eq in 2019. To reduce this, recycling offers the opportunity to keep the embedded carbon in the cycle and thus reduce greenhouse gas emissions. In 2021, only around 33% of recovered plastic waste was mechanically recycled in Germany. To improve this rate, modern and innovative sorting approaches offer the opportunity to increase the recycling rate through higher sorting purity. Such higher sorting purity can be achieved with the Sort4Circle approach, which enables a sorting purity of >99% for 70% of plastics using individual piece separation, tracer-based sorting, and a combined detection unit. The objective of this study was to quantify the environmental impact of the Sort4Circle sorting approach for post-consumer plastic waste.

Methods
To achieve this goal, a life cycle assessment study was conducted. The Sort4Circle approach was compared with alternative recycling systems, particularly the conventional recycling system and chemical recycling, in terms of their climate impact. The functional unit of this life cycle assessment refers to one Mg of post-consumer lightweight packaging. To quantify the potential environmental benefits of recycling, the "avoided burden" approach was used to assign credit to the recycling system. Four scenarios were created, comprising different sorting and recycling processes.

Results and Conclusions
The results of the life cycle assessment have shown that using the Sort4Circle approach in the current system can save up to 737.97 kg CO2-eq per Mg of lightweight packaging compared to the primary production of plastics from fossil raw materials. This corresponds to an increase in net savings of up to 189.69 kg CO2-eq per Mg of lightweight packaging waste compared to the conventional recycling system. The combination of Sort4Circle and chemical recycling can save up to 743.28 kg CO2-eq per Mg of lightweight packaging waste compared to the primary production of plastics and increase the end-of-life recycling ratio to 63%.
This demonstrates that the recycling of plastic waste generally helps to reduce the climate impact. The savings potential achieved through

recycling increases by around 35% with the use of precise sorting processes such as Sort4Circle.

4.08.P-Mo054 A Circular Economy Approach in Concrete Production: LCA of a Dry Washing Process
Anne Rønning, NORSUS; Christian John Engelsen , NORSUS; Sven Henrik Norman , NORSUS; Mehrdad Ghorbani Mooselu, NORSUS; Line Døssland, NORSUS; Rein Terje Thorstensen, NORSUS.

New sustainable concrete production methods aim to reduce waste and carbon emissions by repurposing waste materials. One such method is using recycled aggregates from dry-washing technology for concrete trucks to minimize concrete waste. However, a review of 200+ environmental product declarations (EPDs) from reliable sources like epd-norge.no and ibu-epd.com found that none of them accounted for washing water for trucks or the disposal of sludge in landfills during concrete production. This study aims to analyze the environmental impacts of dry washing systems.

4.08.P-Mo055 A Life Cycle Analysis Model for the Circularity of Permanent Magnet Synchronous Motor Manual Disassembly
Megan Clement, University of Warwick; You Wu, University of Warwick; Stuart R. Coles, University of Warwick.

The challenge currently is how to disassemble Permanent Magnet Synchronous Motors (PMSM). The main issue is the circularity emissions associated with disassemble and recyclability.

Research was carried out using previous literature and models. The reason for this project is to address the lack of recycling processes currently being implemented in industry. The findings investigate whether there are economic and environmental benefits to recycling rare earth elements and understand the industry limitations.

The first step in the method was to understand the challenge and develop a planned solution. The PMSM was chosen as the basis of this model due to the neodymium magnet present. Neodymium is classed as a rare earth element and is classified as critical. Therefore, the functional unit for this LCA model is 1 PMSM motor.

The recycle rates are used from previous literature however, it is assumed that the Electrical steel isn't recycled due to the complexities with silicon present.

The process includes 4 steps requiring electrical input :
- Energy to demagnetise the magnet.
- Energy to run a current through the magnet.
- How to remove coil on stator core.
- Separate Magnets from Lamination Stack.

The mass of materials was based on previous studies and the recycle rates. The process used in this model is the material flow logic. The waste processes are modelled in the direction of the waste produced.

The data gathered showed a motor with a power output of 200kW saved 3kg carbon emissions in comparison to a motor with a power output of 20kW which produced 1.6kg and 80kW motor producing 2.2kg respectively. To conclude this research is beneficial to this topic as there is little information in the domain surrounding this area. With the growing demand for EV's becoming the largest contributor for neodymium demand it is crucial that the disassembly process is considered and the recyclability to prevent depletion of our supplies.

4.08.P-Mo056 Comparative Life Cycle Assessment of Environmental Impacts for Wastewater Treatment Plants and Constructed Wetlands
Seonghyeok Cho, Changwon national university; M. Choi, Changwon national university; S. Kim, Sungilentec.Co., Ltd; J. Park, Changwon national university.

Background and Purpose
This study employs a Life cycle assessment (LCA) to compare the environmental impacts of energy and resource uses during the operational stages of the conventional wastewater treatment plants (WWTP) and constructed wetlands (CW) in Korea, aiming to identify more eco-friendly options. Generally, the quality of contaminated water is improved through WWTPs to reduce the pollution load into the water system. Recently, CWs which are environmentally sustainable and easy to operate have been used as a practical alternative to small and medium-sized WWTPs.
Methods
The environmental impacts at the operating stage of WWTP and CW operated in South Korea were evaluated through LCA. Data on chemical usage and monthly electricity consumption for the entire process were collected for life cycle inventory analysis. Simapro 9.5.0.2v software was used for evaluation, and Ecoinvent 3.9.1v was used for the database. The functional unit was set to 1 m3 of treated water.
Results
LCA results revealed that WWTPs had a relatively higher environmental impact than CWs across all environmental indicators. For WWTPs, the impact categories with the greatest environmental impact were "Ecotoxicity, freshwater-inorganics" (37.73%), followed by "Ecotoxicity, freshwater-part 1" (32.18%) and "Resource use, fossils" (15.38%). In contrast, for CWs, the highest impact was in "Resource use, fossils" (72.35%), followed by "Ecotoxicity, freshwater-inorganics" (6.00%) and "Land use" (5.69%). WWTPs include sludge treatment processes and use a large amount of coagulants and electricity, while CWs use a small amount of methanol and electricity. Consequently, the environmental impact of WWTPs was very high, with coagulants accounting for 74.3% of the total impact.
Conclusions
Since coagulants are the major contributors to the environmental impact of WWTPs, it is suggested that the environmental impact can be reduced by replacing them with coagulants with lower environmental impacts or by developing processes that achieve precipitation without using coagulants.

4.08.P-Mo057 Municipal Solid Waste Regionalization in Europe
Avraam Symeonidis, ecoinvent; Nikolia Stoikou, ecoinvent; Emilia Moreno-Ruiz, ecoinvent.

This study showcases regionalized results of waste treatment activities across Europe.

4.08.P-Mo058 Increasing Transparency: EcoProfiles for Plastic Recyclates
Jonas Hoffmann, GreenDelta GmbH; Max Bringmann, GreenDelta GmbH; Andreas Ciroth, GreenDelta GmbH.

Background and Purpose: In light of the expected tripling of plastic production to over 1100 gigatonnes annually and the associated 15% contribution to global greenhouse gas emissions, robust data for assessing the environmental impacts of plastics is crucial. Current EcoProfiles, which represent Life Cycle Inventories (LCIs) of products from raw material extraction through production, lack transparency and cover mostly primary plastics. Our goal, within the PRIMUS project, is to develop a methodology for creating transparent and detailed EcoProfiles for common mechanically recycled plastics in Europe and to make them publically accessible as partly disaggregated datasets.

Methods: We collaborated with PlasticsRecyclersEurope to collect data from over 20 recycling members using Excel sheets and parameterized models in the openLCA software with the ecoinvent database. This data included various waste streams from more than seven different regions in Europe. We produced both ‘gate-to-gate’ EcoProfiles for mechanical recycling and ‘cradle-to-gate’ profiles, including waste collection and sorting for the convenience of the end-user.

Results: Detailed datasets covering chemicals, water, energy use, and waste management were created for 13 types of recycled plastics. Those inventories will be made available as partly-aggregated datasets later providing a basis for database developers. In fact, our impact analysis showed that recycled HDPE had significantly lower environmental impacts compared to primary HDPE, including a 71% reduction in climate change impact and an 85% reduction in energy resource consumption favoring recycled over primary plastics. However, approaches to close data gaps for overseen particulate matter and microplastic formation will be presented.

Conclusion: These detailed and regionalized EcoProfiles will improve the accuracy and transparency of Life Cycle Assessment databases, aiding more informed and sustainable decision-making in plastic production and recycling. The EcoProfiles, including uncertainty values and data quality assessments, will be publicly available as partly-aggregated datasets, contributing to informed sustainable plastic management. Future work will include assessing microplastic emissions and particulate matter formation.

4.08.P-Mo059 An Lca Framework for the Circular Economy: Accounting for Quality Changes Across Multiple Lifecycles
Jooyoung Park, Seoul National University; Jooyoung Park, Seoul National University; Kyoungphile Nam, Seoul National University.

Evaluating the environmental sustainability of circular economy strategies require accounting for quality changes across multiple life cycles, a factor often overlooked in traditional Life Cycle Assessment (LCA). This study aims to propose an LCA framework to address these issues and apply it to a comparative analysis of the environmental sustainability of plastic chemical recycling versus mechanical recycling. According to our preliminary study, we identified three approaches to incorporate quality changes: 1) a weighted quality model, proposed by Golkaram et al. (2022), integrates various quality aspects into a weighted framework, 2) a market share approach, proposed by Horodytskca et al. (2020), indirectly reflects quality degradation through market share dynamics, and 3) a functionality model, proposed by Hatzfled et al. (2022), quantifies functionality changes over successive uses, We will explore these approaches to assess the environmental impacts of chemical and mechanical recycling of waste plastics and present an integrated LCA framework appropriate to address quality changes across multiple life cycles. Our study aims to provide a more accurate and holistic evaluation of the sustainability of recycling processes, thereby contributing to the adoption of sustainable circular economy practices.

4.08.P-Mo060 What Can We Learn From Past Life Cycle Assessments of Biosolids Processing Systems?
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BACKGROUND AND PURPOSE

Life cycle assessment (LCA) is increasingly used to evaluate biosolids processing systems and guide decisions on technology selection and system optimisation. However, significant disparities in methodological practices and assessment outcomes exist in past applications of LCA to biosolids processing systems, which can hamper the credibility of LCA results and limit the utility of existing LCA data for decision-making. This study aims to understand the methodological variations and the resulting discrepancies in LCA outcomes of biosolids processing systems and perform a harmonisation of results to enhance the comparability and validity of conclusions from previous LCAs.

METHODS

This study reviewed 72 published LCAs on biosolids processing systems, analysing variations in methodological choices, inventory data and assessment outcomes. Harmonisation of system boundary and background systems was performed on global warming potential (GWP) results to enable the comparison and aggregation of previous LCA results. A novel method, partial harmonisation, was used to identify key methodological choices and process parameters causing variability in assessment results across studies.

RESULTS

Significant variations were observed in the methodological practices of previous studies, particularly in system boundary definitions and approaches used to account for biosolids processing benefits. Key sources of variation identified through partial harmonisation include the background electricity mix, boundary conditions for energy recovery from biosolids anaerobic digestion and incineration, and the amount of mineral fertiliser substituted by the land application of digestate. Harmonisation resulted in a 17% and 21% reduction in the standard deviation of GWP results for anaerobic digestion and incineration, respectively. However, no conclusive evidence was found regarding the environmental superiority of either biosolids anaerobic digestion or incineration.

CONCLUSION

This study revealed significant discrepancies in both the methodological practices and outcomes from past LCAs on biosolids, highlighting the need for advancements to improve the robustness of LCA for biosolids processing systems, including standardising methodological practices and further research on key inventory data. Standardisation efforts should prioritise the key LCA inputs identified as major sources of variation in the results from partial harmonisation.

4.09 - LCA Advances for Water Engineering Towards Circular Economy

4.09.T-01 Life Cycle Assessment of Innovations in Water Treatment for PFAS Removal: What Do We Know?
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Per- and polyfluorinated alkyl substances (PFAS) are highly fluorinated anthropogenic compounds that exist in numerous forms. Studies have shown that human exposure to PFAS, mainly through drinking water and food, can lead to cancer risks, fetus malformation and interference with the endocrine system. As more is understood regarding the toxicological impacts of PFAS, interest in removing these substances from drinking water sources is increasing and novel technologies are being developed. The purpose of this review is to help prioritize LCA research activities by mapping current LCA coverage of PFAS treatment technologies and identifying important knowledge gaps. To do that, a scoping review was developed with the aim of gathering information about the use of Life Cycle Assessment (LCA) in sustainability analysis on novel technologies to remove PFAS from water matrices. In total, eight papers matched the eligibility criteria set for this literature review, which were developed between 2019 and 2023. In neither of these articles was the LCA goal evidently stated, making the analytical process difficult. The water sources analyzed by the studies include groundwater, wastewater and waste of water treatment. Moreover, the technologies evaluated through LCA were used to separate PFAS from the aqueous sources and, in some cases, destroy them. However, the assumption of complete PFAS destruction leads to an underestimation of PFAS emissions in the LCA, as it fails to account for the volatilization or breakdown of PFAS into other compounds. A significant limitation identified across the articles is the incorporation of PFAS into LCA studies without verifying the availability of PFAS-related characterization factors in USEtox, the methodology predominantly utilized for evaluating toxicity effects. This omission can result in data gaps and underestimation of toxicity-related impacts, as the absence of PFAS characterization factors means their impact cannot be accurately reflected in LCA calculations. In conclusion, this scoping review addresses the main gaps encountered in life cycle assessments of novel technologies to remove PFAS from waters and proposes ideas to improve the methods used when developing LCA.

4.09.T-02 Environmental Impact of Integrating Decentralised Urine Treatment in the Urban Wastewater Management System: A Comparative Life Cycle Assessment

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Background and Purpose

Decentralised treatment of urine source-separated streams integrated into the urban wastewater management system, leading to so-called “hybrid solutions”, could maximise resource recovery while minimising environmental impacts at the centralized wastewater treatment plant (WWTP). While previous studies have compared urine separation systems to conventional WWTPs, none has considered an integrative approach encompassing operation, infrastructure (treatment system and building pipes), different treatment options, state-of-the-art WWTP and process modelling using real plant data. Therefore, this study aims to conduct a consequential LCA to compare hybrid urine treatment technologies to evaluate which is the most sustainable option for city block-level treatment compared to a centralised wastewater treatment with low energy consumption and N2O emissions.

Methods

Three hybrid systems were compared to one state-of-the-art centralised WWTP (reference scenario). A fictional high-density city was designed to model the system. Residents separate their urine which is collected and treated on-site, while blackwater and greywater are sent to a central treatment plant. 1 population equivalent (PE) of wastewater treatment per day was chosen as the functional unit. The system boundary encompassed urine collection, treatment, transportation of produced fertiliser, and centralised WWTP. Infrastructure and operational data are considered for urine treatment scenarios, while only operational data are accounted for in centralised WWTP scenarios.

Results

The results show that urine source separation improves the environmental performance in state-of-the-art WWTPs (hybrid treatment scenarios), except for its impact on global warming (GW), making it especially beneficial in facilities with high N2O emissions and electricity use. The fact that the centralised treatment plant performs better in the global warming impact category differs from previous studies that concluded that urine source separation has a lower GW impact than municipal WWTPs. A break-even analysis of N2O emissions in the activated sludge shows the hybrid scenarios and the reference WWTP have similar GW impacts at emission factors between 0.8% and 1.5% of influent nitrogen.

Conclusion

This study suggests that hybrid wastewater treatment systems could be used as a strategy for improving the environmental impacts of WWTPs with high N2O emissions and electricity consumption.

4.09.T-03 Assessing Sewage Sludge Treatment from a Life Cycle Perspective – Critical Gaps in the Impact Assessment of Per- and Polyfluoroalkyl Substances

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Background and Purpose

The treatment of sewage sludge from wastewater treatment plants has been a challenge over time. This is mostly due to its high moisture content but also due to raised awareness and concern linked to the potential presence of toxic compounds, such as per- and polyfluoroalkyl substances (PFAS), and to their potential toxicity impacts on human health and the environment. There is a lack of fundamental knowledge on mecha-nisms that is important for the identification and quantification of PFAS and, there is uncertainty regarding the degradation rates of PFAS and the products that result from this process of degradation. On the other hand, there are several impact assessment methods that can be applicable to PFAS, however, they have associated weaknesses.

The aim of this study is to assess the treatment of wastewater sewage sludge by anaerobic digestion fol-lowed by pyrolysis of the resulting digestate, and to compare pyrolysis with anaerobic digestion treatment, over a life cycle perspective. The goal is two-fold: to assess the potential human health and environmental impacts of PFAS that may be present in the wastewater sewage sludge by applying different impact as-sessment methods; and to contribute to the ongoing discussion about PFAS fates in pyrolysis products and emissions.

Methods

The LCA will be conducted according to the ISO 14040 and 14044 standards. The wastewater sewage sludge treatment system will be modelled in the LCA software SimaPro V9.6 Multiuser and the ecoinvent database V3.9 will be used to model processes in the background system. The following impact assessment methods will be applied: UseTox, TraCi, ReCiPe and EMS.

Results

Results will be presented comparing anaerobic digestion and pyrolysis in the treatment of wastewater sewage sludge, and differences in results will be discussed when different impact assessment methods are considered.

Conclusions

This study aims to support decision making in the implementation of emerging technologies linked to wastewater sewage sludge treatment by addressing its potential toxicity impacts on human health and the environment. Results show that pyrolysis applied to wastewater sewage sludge treatment leads to a decrease in the PFAS emissions compared to anaerobic digestion and human health and environmental impacts linked to the treatment of wastewater sewage sludge present significant differences when different impact assessment methods are applied.

4.09.T-04 Sustainability Assessment of Sediment Dredging, Possibilities and Challenges

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Beyond navigational purposes, dredging has the potential to play a vital role in environmental conservation by creating or restoring habitats and removing contaminated sediments to improve water quality and aquatic ecosystem health and to recycle materials into new products. Despite the crucial role of dredging in sustainable coastal and environmental management, the environmental impacts of dredging in a life cycle perspective have not been well investigated. As development in technology allows for more marine development and ecosystem impacts in the marine environment increase, so does the need to measure these impacts increase. This study aims to provide insights into the environmental sustainability of dredging by exploring the environmental impacts from different scenarios of both clean and polluted sediment dredging in a river/coastal system.

4.09.P - LCA Advances for Water Engineering Towards Circular Economy

4.09.P-Mo061 LCA of Nutrients and Carbon Circulation From Connecting Aquaculture and Agriculture With Biochar From Forestry

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Background and purpose
National and international research programs are aiming at reducing undesired carbon (C), nitrogen (N), and phosphorus (P) waste and emissions by implementing technologies that capture emissions and transform waste into resources in a circular economy. Biochar production from biomass pyrolysis and its use in agriculture is a promising technology to mitigate climate change and improve soil quality. In this study, we evaluate the concept of controlling C, N, and P flows by means of a biochar filter in aquaculture for moving nutrients as well as stable carbon to agriculture. The purpose is to guide system designers in technology development that provides an added function to biochar, thereby supporting sustainable agricultural and aquaculture practices.

Methods
Through prospective life cycle assessment (LCA), the study assesses the life cycle environmental impacts of different scenarios for nutrients and carbon circularity, by studying the involved technologies separately, as today, and in combination in a connected future system. The technologies are pyrolysis of forestry biomass, a recirculating aquaculture system (RAS) for fish production, and the use of biochar and a fertilizer in agriculture – in the combined case a fish waste nutrient-enriched biochar. Biochar is thereby used as an innovative filter technology to capture nutrients in the recirculating water in aquaculture. Since the function of a biochar filter in aquaculture is not yet fully understood, different solutions will be explored, with a vision to fully replace the current biofilter and thereby prevent reactive nitrogen from being inactivated and mineralized to nitrogen gas. The LCA explores and looks for optimization pathways for carbon and nutrient (re)cycling in the combined aquaculture-agriculture system.

Results
By examining both individual components and the entire system, the preliminary results indicate that: 1) integrating RAS technology with pyrolysis as proposed will not significantly increase the global warming potential, cumulative energy demand, acidification, or abiotic depletion compared to pyrolysis alone; 2) the RAS will have an impact on eutrophication and land occupation, mainly due to fish feed production; and 3) use of biochar in agriculture provides environmental benefits for all the environmental impact indicators since carbon sequestration and N2O emissions reductions occur.

Conclusions
This study underscores the potential of integrating innovative technologies and circular economy principles to address environmental challenges and optimize nutrient cycling within combined aquaculture-agriculture systems. Further research and refinement of this innovative integrated system is essential to realize the full environmental and sustainability potential.

4.09.P-Mo062 Evaluating the Water Use Impact in the EU's Renewable Hydrogen Supply Chain: A Life Cycle Assessment

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In the REPowerEU plan (2022), the EU established an ambitious target to produce and import a total of 20Mt of renewable hydrogen by 2030, to boost the sustainability and resilience of Europe's energy system. Yet, the costs associated with the hydrogen supply chain remain a significant barrier. Importing renewable hydrogen from regions where renewable electricity production potential is large and low-cost may cut expenses. Therefore, is crucial to assess the environmental impacts of such practices. Through a life cycle assessment (LCA) we investigated these impacts using the Environmental Footprint method, including an analysis on freshwater availability. This factor is critical, as water scarcity could emerge as a limiting factor in hot, arid regions with substantial solar energy potential. In these locations, the implementation of seawater desalination technology may offer a solution to alleviate the pressure on freshwater resources.

In our case study, we leveraged solar energy as the primary source of renewable electricity for hydrogen production, and evaluated the environmental impacts of various hydrogen delivery methods, including compressed and liquid hydrogen, and several chemical carriers. We compared the impacts transportation via pipeline or shipping wherever applicable. We also considered alternative scenarios involving on-site hydrogen production. Within this comprehensive LCA framework, we conducted a sensitivity analysis that includes replacing freshwater with desalinated seawater for hydrogen production, focusing on the environmental trade-offs in solar-abundant yet water-scarce regions.

The findings of our research reveal that the desalination of seawater substantially diminishes the water use for a majority of hydrogen delivery scenarios. Nevertheless, it becomes evident that on-site hydrogen production generally consumes less water. It is also observed that the heightened energy demands of desalination, along with subsequent purification processes, lead to an average increase of 4% in climate change-related impacts. Thus the single-score analysis reveals that different water supply do not significantly lower the overall environmental impact.

In conclusion, our LCA provides critical insights into the environmental trade-offs associated with various hydrogen delivery methods. Policymakers and industry stakeholders must weigh these considerations carefully to advance the EU's clean energy objectives without compromising environmental integrity.

4.09.P-Mo063 Life cycle assessment of an in-situ treatment of an open municipal drain in Delhi- environmental aspects and impacts

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The veins of any metropolis are its urban city drains. In an ideal situation, the sewage drains, and the storm water drains are separate non-interacting systems. However, the reality is complex as sometimes both or either plays the part for addressing the rainwater and the domestic discharges. The increasing population and habitat pressure have however, forced the drains to face several challenges including overflows, shock loadings and presence of various organic, inorganic and emerging pollutants. The volume of wastewater produced is steadily rising with no lasting solution for treating large quantities of sewage. Untreated wastewater flowing through drains merges with water bodies, posing significant pollution and health risks due to organic buildup and nutrient concentration. Furthermore, there are no available land near these drains for ex-situ treatment. In-situ remediation methods offer a more practical alternative to conventional sewage treatment plants, as they are simpler to build, operate, and manage, requiring no additional external space or energy than an equivalent ex-situ treatment plant. Also coping with new stringent norms for achieving the BOD level below 10mg/l is also a challenge for already operational STPs. Therefore, it is essential that novel approaches like in-situ treatment are implemented to minimize the pressure on downstream treatment plants. This paper undertakes a Life Cycle Assessment (LCA) of one such implemented scheme with the objective to interlink this with the concept of environmental aspects and impacts which is the cornerstone of any environmental impact assessment and ISO-14001. The paper also explores the rapid feasibility of such systems for scalability so that environmental protection and human health are ensured.

Keywords: Life cycle assessment, urban drains, circular economy, in-situ wastewater treatment

4.09.P-Mo064 Environmental Impacts of Biochar Filters for Onsite Wastewater Treatment

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Background and Purpose

In Sweden there are around 700 000 onsite wastewater treatment systems (OWTS). Lab scale experiments and pilot projects indicate that biochar is a promising filter material for removal of pollutants in onsite wastewater systems, but the environmental impacts of this system have not been quantified. This study evaluated the environmental impacts of biochar as a filter media, and compared them to sand, a common filter media used in onsite wastewater treatment.

Methods

Two biochar filters were modeled as alternatives to sand filters in OWTS in normal and sensitive areas, as defined by Swedish government recommendations. Three impact categories were chosen: climate impact, acidification and eutrophication. Since biochar filters is a novel technology, with large uncertainty in data and several possible supply chains and end-of-life, a parameterized life cycle assessment with global sensitivity analysis was conducted. Scenarios with different combinations of biochar supply chain, end-of-life, and different background energy systems, were simulated.

Results

The climate impact of the biochar filter varied considerably, being considerably higher and lower than that of the sand filter, depending on scenario. The eutrophication impact of the biochar filters was similar to that of the sand filter, and the acidification impact was higher than that of the sand filter in sensitive areas, and lower in normal areas. Contribution analysis and identification of sensitive parameters show that the same processes contributed most to the total impacts as well as variation in these for all biochar systems, namely direct emissions to air and water from the wastewater treatment process, biochar supply chain and biochar end-of-life.

Conclusions

Biochar filters can be an environmentally sound alternative for onsite wastewater treatment. However, the environmental impact of the biochar filters varied considerably both across different scenarios, and within the scenarios. For the biochar filter to have lower environmental impacts than the sand filter, the higher impacts from biochar production compared with sand production and end-of-life have to be compensated by carbon storage in biochar and additional benefits. This study is the first environmental assessment of biochar filters in OWTS and has identified sensitive parameters, key uncertainties and knowledge gaps to be further assessed in future studies.