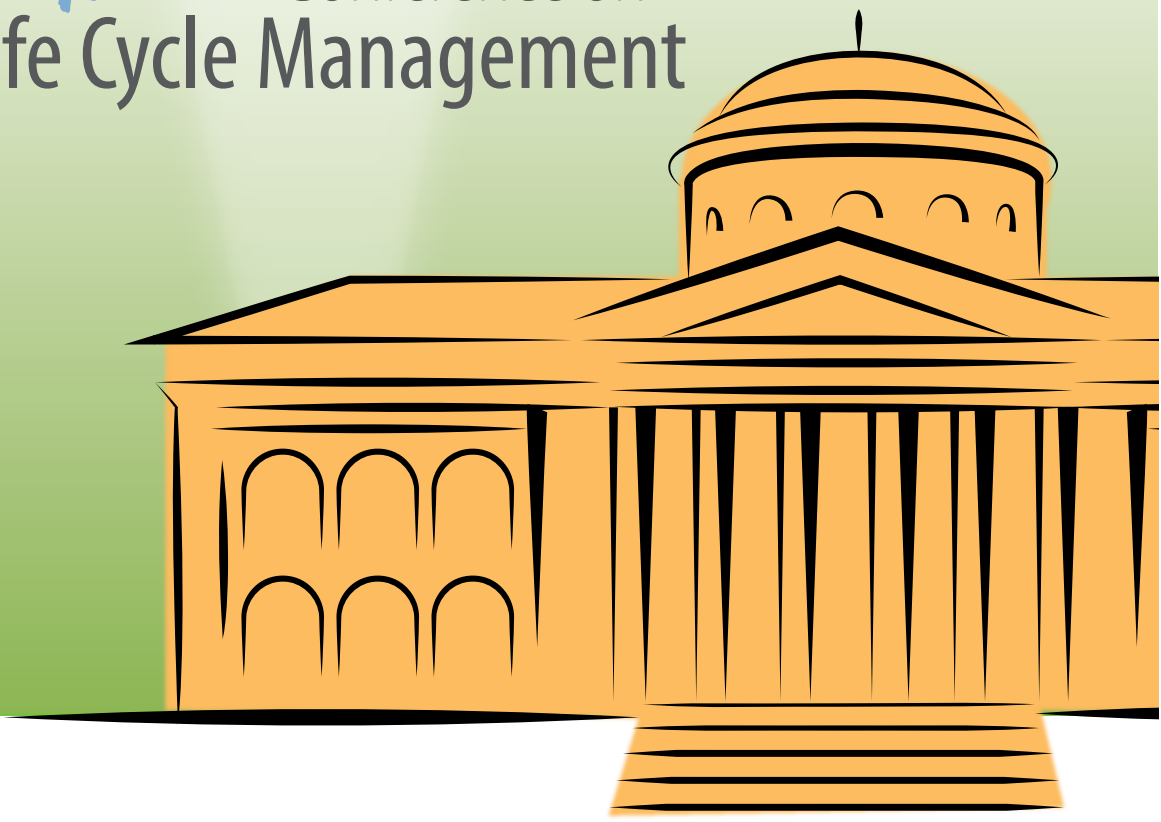
LCM 2025
PALERMO

12th International Conference on Life Cycle Management



ISBN: 978-3-00-084166-8

Institute of Sustainability in Civil Engineering

RWTH AACHEN UNIVERSITY

HITACHI

Circular
Innovation & Sustainability

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Session 1.01: Communication and Raising Circular Economy Awareness via Robust LCA Part I

Session Chair: Matthias Finkbeiner, Technische Universität Berlin, Germany
Session Chair: Stephane Morel, ESCP Business School, France

Session 1.02: Future-Proof Verification processes in LCA

Session Chair: Alexander Forell, Makersite, Germany
Session Chair: Gabriella Arcese, Niccolò Cusano University, Italy

Session 1.03: Pathways to Net-Zero: Industrial Decarbonization & Green Energy Part I

Session Chair: Nele De Belie, Ghent University, Belgium
Session Chair: Pascal Di Croce, EuLA, Belgium

Session 1.04: Life Cycle Metrics for industry and policymakers: From Innovation to Integration I

Session Chair: Luca Zampori, PRé Sustainability, The Netherlands
Session Chair: Davis Jose, INaB - RWTH, Germany

Session 1.05: LCA in the mining and metals industry: Current practices and challenges

Session Chair: Johannes Arnold Drielsma, Drielsma Resources Europe, The Netherlands
Session Chair: Stéphanie Muller, BRGM, France

Session 1.06: Sustainable Underground Construction In Pipeline Infrastructures

Session Chair: Stefan Schmitz, TRACTO-TECHNIK GmbH & Co. KG, Germany
Session Chair: Andreas Redmann, Kunststoffrohrverband e.V., Germany

Session 1.07: LCA in Policy: Frameworks, Compliance & Placement Part I

Session Chair: Antonio Valente, ecoinvent, Switzerland
Session Chair: Diego Iribarren, IMDEA Energy, Spain

Session 1.08: PCF data: Achievements and challenges for sector-specific guidelines in industry

Session Chair: Martina Prox, iPoint-Systems gmbh, Germany
Session Chair: Peter Rudolf Hans Saling, BASF SE, Germany

Session 1.09: Social Sustainability: Data & Method Advancements Part I

Session Chair: Luigia Petti, UNIVERSITÀ "G.D'ANNUNZIO", Italy
Session Chair: Sonia Valdivia, WRFA, Switzerland

Session 1.10: Sustainable mobility solutions Part I

Session Chair: Stephan Krinke, Fraunhofer IST, Germany
Session Chair: Katharina Gompf, BMW Group, Germany

Session 1.11: Circular Textiles: how LCA can Support the Transition

Session Chair: Archana Datta, UNEP, France
Session Chair: Claudia Giacovelli, UNEP, France

Session 1.12: Healthcare LCA

Session Chair: Rose Nangah Mankaa, INaB-RWTH Aachen, Germany
Session Chair: Scott McAlister, University of Melbourne, Australia

LP1: Lunch & Poster

Session 1.13: Digital LCA/PCF data sharing for Collaboration & Innovation

Session Chair: Martin Baitz, Sphera Solutions GmbH, Germany
Session Chair: Massimo Collotta, Henkel AG & Co. KGaA, Germany

Session 1.14: Communication and Raising Circular Economy Awareness via Robust LCA Part II

Session Chair: Matthias Finkbeiner, Technische Universität Berlin, Germany
Session Chair: Stephane Morel, ESCP Business School, France

Session 1.15: LCM for the Biobased Economy: Innovative Methods and Practices Part I Part I

Session Chair: Thomas Schaubroeck, Luxembourg Institute of Science and Technology, Luxembourg
Session Chair: Tamara Coello García, Cesefor, Spain

Session 1.16: LCA & LCM for Improved Energy Decision-Making Part I

Session Chair: Luka Smajila, KTH - Royal Institute of Technology, Sweden
Session Chair: Ketan Vaidya, ex-Northvolt AB, Sweden

Session 1.17: Textile/Apparel: B2B & B2C Communication Challenges

Session Chair: Enrico Benetto, Luxembourg Institute of Science and Technology, Luxembourg
Session Chair: Federico Brugnoli, SPIN360, Italy

Session 1.18: LCA & Circularity to Improve Road Construction Env. Performance Part I

Session Chair: Nicolás Héctor Carreño Gómez, VINCI Construction Shared Services GmbH, Germany
Session Chair: Davide Lo Presti, Universita degli studi di Palermo, Italy

Session 1.19: Life Cycle Based Tools and Data Science Interactions Part I

Session Chair: Alessandro Manzardo, University of Padova, Italy
Session Chair: Monia Niero, Sant'Anna School of Advanced Studies, Italy

Session 1.20: Evaluations of Circular and Low Carbon Plastic Value Chains towards sustainability Part I

Session Chair: Tomas Ekvall, Tomas Ekvall Research, Review & Assessment (TERRA), Sweden
Session Chair: Christian Krüger, BASF, Germany

Session 1.21: LCM for the Biobased Economy: Innovative Methods and Practices Part II

Session Chair: Thomas Schaubroeck, Luxembourg Institute of Science and Technology, Luxembourg
Session Chair: Tamara Coello García, Cesefor, Spain

Session 1.22: LCM implementation in SMEs

Session Chair: Yahong Dong, Macau University of Science and Technology, Macau S.A.R. (China)
Session Chair: Mark Goedkoop, Product-ecology, The Netherlands

Session 1.23: Thermochemical Waste Management: Status & Outlook

Session Chair: Filomena Ardolino, University of Campania "Luigi Vanvitelli", Italy
Session Chair: Umberto Arena, University of Campania Luigi Vanvitelli, Italy

Session 1.24: LCA & Circularity to Improve Road Construction Env. Performance Part II

Session Chair: Nicolás Héctor Carreño Gómez, VINCI Construction Shared Services GmbH, Germany
Session Chair: Davide Lo Presti, Universita degli studi di Palermo, Italy

DAY 2

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Session Chair: Nele De Belie, Ghent University, Belgium
Session Chair: Pascal Di Croce, EuLA, Belgium

Session 2.02: Life Cycle Metrics for industry and policymakers: From Innovation to Integration II

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Session Chair: An De Schryver, PRé sustainability, The Netherlands

Session 2.03: Advancing Polymer Recycling: Methods & Policy for a Sustainable Transition

Session Chair: Paola Federica Albizzati, Joint Research Centre - European Commission, Spain
Session Chair: Carlo Brondi, CNR, Italy

Session 2.04: Methodologies and Tools for Sustainable Agriculture and Food Value Chains Part I

Session Chair: Andrea Di Maria, University of Liege, Belgium
Session Chair: Olubukola Olumuyiwa Tokede, Deakin University, Australia, Australia

Session 2.05: Regional Sustainability via Life Cycle Instruments Part I

Session Chair: Takunda Yeukai Chitaka, University of Bordeaux, France
Session Chair: Pia Wiche, EcoEd, Chile

Session 2.06: Nutritional LCA for Sustainable Agri-Food Management Part II

Session Chair: Silvia Zingale, Agroscope, Switzerland
Session Chair: Gianluca De Nardi, EcorNaturaSì Spa, Italy

Session 2.07: Mass Balance Chain of Custody and LCA methodology and practices

Session Chair: Markus Berger, University of Twente, The Netherlands
Session Chair: Guy Castelan, PlasticsEurope, Belgium

Session 2.08: Policy Coherence: Tools and best practices for an efficient and effective sustainable transition

Session Chair: Laura Garcia Herrero, EC - JRC, Italy
Session Chair: Martina Orefice, Joint Research Centre, Italy

Session 2.09: LCA in Policy: Frameworks, Compliance & Placement Part II

Session Chair: Diego Iribarren, IMDEA Energy, Spain
Session Chair: Antonio Valente, ecoinvent, Switzerland

Session 2.10: Social Sustainability: Data & Method Advancements Part II

Session Chair: Manuela D'Eusanio, Università degli Studi "G.d'Annunzio" di Chieti-Pescara, Italy
Session Chair: Isabel Susan Wolf, TU Berlin, Germany

Session 2.11: Sustainable mobility solutions Part II

Session Chair: Katharina Gompf, BMW Group, Germany
Session Chair: Tobias Viere, Pforzheim University, Germany

Session 2.12: LCSA advancements and implementation in building Part I

Session Chair: Matthias Fischer, Fraunhofer Institute for Building Physics IBP, Germany
Session Chair: Jana Gerta Backes, Meo Carbon Solutions GmbH, Germany

LP2: Lunch & Poster

Session 2.13: Boosting LCM with AI, Machine Learning & Data Science Tools

Session Chair: Antonino Marvuglia, Luxembourg Institute of Science and Technology, Luxembourg
Session Chair: Peter Rudolf Hans Saling, BASF SE, Germany

Session 2.14: Biogenic Carbon: Challenges of Modelling & Accounting in LCA

Session Chair: Michael Sturges, RISE Research Institutes of Sweden, United Kingdom
Session Chair: Mateo Saavedra del Oso, Stora Enso, Finland

Session 2.15: Dynamic and Prospective LCA Part I

Session Chair: Hanna Pihkola, VTT Technical Research Centre of Finland, Finland
Session Chair: Friedrich Jasper, Karlsruhe Institute of Technology (KIT), Germany

Session 2.16: Using LCSA for Industry Decision-Making Part I

Session Chair: Nils Jäger, thyssenkrupp Steel Europe AG, Germany
Session Chair: Julian Suer, thyssenkrupp Steel Europe AG, Germany

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Session 2.22: Filling the Gaps in Life Cycle Assessments of Upstream Materials for the Sustainable Deployment of Battery Ecosystems

Session Chair: Sophia Roy, Polytechnique Montréal, Canada
Session Chair: Ketan Vaidya, ex-Northvolt AB, Sweden

Session 2.23: LCA & Natural Capital: Driving Nature-Positive Outcomes

Session Chair: Alexandra Evans, Vito, Belgium
Session Chair: Sun-Hea Hong, University of Stuttgart, Germany

Session 2.24: LCSA for decision making in energy systems

Session Chair: Maurizio Cellura, Università di Palermo, Italy
Session Chair: Guido Sonnemann, Université de Bordeaux, France

DAY 3

Session 3.01: Handprints as a method to accelerate the sustainable Transition

Session Chair: Gregory A. Norris, MIT, United States of America
Session Chair: Sonia Valdivia, WRFA, Switzerland

Session 3.02: LCT based Tool for Sustainability in Industry

Session Chair: Stephan Krinke, Fraunhofer IST, Germany
Session Chair: Juan Felipe Cerdas Marin, Technical University of Applied Sciences Würzburg-Schweinfurt, Germany

Session 3.03: LCM for an enhanced circularity in steel and other metals

Session Chair: Luiz Kulay, University of São Paulo, Brazil
Session Chair: Diego C Magalhaes, ArcelorMittal, Brazil

Session 3.04: LCSA Insights: Actionable Solutions for Global Challenges

Session Chair: Jana Gerta Backes, Meo Carbon Solutions GmbH, Germany
Session Chair: Alessandra Zamagni, Ecoinnovazione, Italy

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Session Chair: Pia Wiche, EcoEd, Chile

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Session Chair: Silvia Zingale, Agroscope, Switzerland

Session 3.07: Data Creation & Exchange Tools: Transparency First

Session Chair: Stephan Pfister, ETH Zurich, Switzerland
Session Chair: Emilia Moreno Ruiz, ecoinvent, Switzerland

Session 3.08: Downscaling SDGs & Planetary Boundaries for Products & Organizations

Session Chair: Andreas Barth, Wood K Plus Kompetenzzentrum Holz GmbH, Austria
Session Chair: Naeem Adibi, WeLOOP, France

Session 3.09: Tackling climate risks and nature dependencies for a healthy future

Session Chair: Jan Bollen, ArcelorMittal Europe, Belgium
Session Chair: Giulia Maggiora, Quantis, Italy

Session 3.10: LCM in Rail, Aviation and other transport systems

Session Chair: Davide Bonaffini, Hitachi Rail, Italy
Session Chair: Ladji Tikana, International Copper Association, Germany

Session 3.11: Ecotox/Toxicity Metrics for Portfolio Assessment in Chemicals

Session Chair: Tomas Vilhelm Rydberg, IVL Swedish Environmental Research Institute, Sweden
Session Chair: Peter Rudolf Hans Saling, BASF SE, Germany

Session 3.12: LCSA advancements and implementation in building Part II

Session Chair: Matthias Fischer, Fraunhofer Institute for Building Physics IBP, Germany
Session Chair: Pamela Haverkamp, INaB - RWTH, Germany

LP3: Lunch & Poster

Session 3.13: Sustainability & Circularity

Session Chair: Cécile Bulle, CIRAIG, Canada, Canada
Session Chair: Anna Luthin, Mitsui Chemicals Europe GmbH, Germany

Session 3.14: Dynamic and Prospective LCA Part II

Session Chair: Jessica Hanafi, Life Cycle Indonesia, Indonesia
Session Chair: Suzana Ostojic, INaB - RWTH Aachen, Germany

Session 3.15: Data Creation & Exchange Tools: Transparency First

Session Chair: Stephan Pfister, ETH Zurich, Switzerland
Session Chair: Emilia Moreno Ruiz, ecoinvent, Switzerland

Session 3.16: LCM's Future: Collaboration, Innovation & Impact

Session Chair: Philip Strothmann, Forum for Sustainability through Life Cycle Innovation e.V., Germany
Session Chair: Anna Wikström, Sweden

Session 3.17: Using LCSA for Industry Decision-Making Part II

Session Chair: Nils Jäger, thyssenkrupp Steel Europe AG, Germany
Session Chair: Julian Suer, thyssenkrupp Steel Europe AG, Germany

Session 3.18: Methodologies and Tools for Sustainable Agriculture and Food Value Chains Part II

Session Chair: Andrea Di Maria, University of Liege, Belgium
Session Chair: Roland Meyer, INaB - RWTH Aachen, Germany

Presentations

Session 1.01: Communication and Raising Circular Economy Awareness via Robust LCA Part I

Time: Wednesday, 10/Sept/2025: 9:35am - 11:05am
Session Chair: Matthias Finkbeiner, Technische Universität Berlin, Germany
Session Chair: Stephane Morel, ESCP Business School, France

Assessing and communicating potential environmental benefits of the Circular Economy: A case study on ski core circularity

Ulrike Kirschnick[1], Sara Casale[2], Herbert Gruber[2], Roland Pomberger[3], Ewald Fauster[1]

[1]Processing of composites and design for recycling, Technical University Leoben, Austria; [2]Head Sport GmbH, Austria; [3]Waste Processing Technology and Waste Management, Technical University Leoben, Austria

The R-strategies of the Circular Economy framework aim to extend the lifespan of a product and its parts through reuse, repair, refurbishment and remanufacturing, if reducing the consumption of resources is not possible in the first place. The use of the ski core in multiple ski lives does not only increase resource efficiency but can potentially also lead to a decrease in environmental impacts. These environmental benefits require verification as well as communication to the consumer to enhance likeliness of the consumer returning the ski to the manufacturer to enable reuse. The study at hand discusses different methodological choices to determine environmental impacts using Life Cycle Assessment (LCA). The reuse of the material is considered per ski i) for consumer behaviour in the ski rental sector, where the ski core can be used five times; ii) through equally allocating impacts between the first and second life of the ski, and through the comparison of two approaches to model recycling for the remanufacturing notion, namely iii) the 100/0 and vi) the Circular Footprint Formula. The Life Cycle Inventory comprises all materials and manufacturing steps in the first life as well as transport, additional material and manufacturing inputs and outputs to remanufacture the ski for its second life, which can be with the same customer as the first life or as part of a newly sold product. The selected Life Cycle Impact Assessment method is EF3.1 to discuss potential trade-offs between impact categories. Next to the comparison of environmental impacts per LCA model, the influence of the choice of modelling on communication to the company management and to the consumer is discussed. The discussion focuses on the LCA models' comprehensiveness, inference on product competitiveness, and activation of the desired consumer behavior to partake in the return system.

Joint application of Life Cycle and Criticality Assessments: A Case Study on Lithium-Ion Batteries

Dieuwertje Schrijvers[1], Emilie Guilvert1, Anish Koyamparambath[2], Guido Sonnemann[2], Frédéric Lai[3], Marion Devienne[4], Philippe Osset[4], Naeem Adibi[1]

[1]WeLOOP, France; [2]ISM-CyVi; [3]BRGM; [4]SCORELCA

Critical raw materials (CRMs) are increasingly prioritized in regulations and strategic decisions at both the European political level and within companies. Life cycle assessment (LCA) has been used in several criticality studies to evaluate the environmental impacts of CRMs from various perspectives. Conversely, LCA offers methods to assess the sustainability of resource use, such as those addressing material dissipation and short-term supply risks. The SCORE LCA project "LCA and Criticality" aims to better integrate criticality into LCA, enabling LCAs to more effectively account for environmental dimensions in criticality analyses

and support strategic decision-making.

An analysis of the state-of-the-art was performed and revealed opportunities to align LCA and criticality methods, especially in the context of lithium-ion batteries, which depend on CRMs like lithium, cobalt, and aluminium. Rising battery demand for electric vehicles and energy storage intensifies supply risks, emphasizing the need for secure sourcing, recycling, and substitution. Case studies were conducted to explore these synergies, including: (1) a dual analysis of environmental and criticality aspects for two types of lithium-ion batteries, (2) an environmental assessment of relocating lithium hydroxide production to Europe rather than relying on imports, and (3) a sensitivity analysis of Europe's recycling potential to achieve the Critical Raw Materials Act's goal of 25% recycling by 2030.

The case studies were developed using advanced tools like Simapro and ecoinvent for LCA and IRTC framework, GeoPolRisk and ESSENZ for criticality assessments. They were assessed based on their relevance to LCA and criticality communities, potential applications by companies and policymakers, data requirements, and model maturity. Recommendations are provided based on the state-of-the-art analysis, methodological synthesis, and case study results to guide sustainable resource management and policy development.

Siemens approach for a Robust Eco Design: Insights and an outlook after five years of implementation

Johannes Auer, Karin Uebelhoer

Siemens AG, Germany

Siemens is a global technology group with a presence in nearly every country. We focus on automation and digitalization in the process and manufacturing industries, intelligent infrastructure for buildings and distributed energy systems, smart mobility solutions for rail transport, and medical technology and digital healthcare services.

As a dedicated technology company, Siemens is developing technologies that drive the digital transformation of industries, smart infrastructure, and sustainable mobility. Our goal is to address global challenges and achieve sustainable growth.

Ecodesign, or the sustainable design of goods and services, aims to optimize and enhance the environmental compatibility of technology. It is a crucial part of our design strategies to protect the environment, make better use of finite resources, and preserve ecosystems for future generations. Siemens employs the Robust Eco Design (RED) approach, which outlines the requirements for applying and implementing these design strategies, as a core part of our corporate DNA.

Developed in 2020, the Robust Eco Design (RED) approach was introduced to systematically enhance the environmental compatibility of Siemens' offerings. It is based on three key principles: i) Application Perspective, ii) Solid Foundation, and iii) Dematerialization. The application perspective involves identifying and prioritizing ecodesign requirements for relevant product families. The solid foundation quantitatively assesses and documents potential environmental impacts. Dematerialization derives concrete design optimizations based on the application perspective and the solid foundation.

This conference contribution will explain the background of these key principles and their implementation in product life cycle management. It will also elaborate on achievements and key success factors for efficient and effective implementation, based on lessons learned over five years. Finally, we will explore extending the application of RED to software and service-based offerings.

Circularity and Ferrer's Packaging for Good Program

Sergi Arnau Castel[1], Beatriz Cuende Negra[1], Laura Batlle Bayer[2], Ilonka Zsolt Fradera[1]

[1]Grupo Ferrer Internacional, Spain; [2]Anthesis, Spain

Ferrer, a Spanish pharmaceutical company and certified B Corp, is dedicated to advancing packaging circularity as a pivotal strategy for decarbonization and waste reduction. Since 2020, the company has been implementing its 'Packaging for Good Program,' a comprehensive initiative to enhance material efficiency in packaging production. The development of this program was divided into three phases:

- Phase 1 focused on creating a comprehensive packaging database that detailed the environmental impact of each component. It also included the development of a sustainable packaging model policy and the creation of a catalog of eco-design strategies.

- Phase 2 focused on the implementation process, which involved developing a reporting system and enhancing internal communication.

- Phase 3 centered on analyzing the eco-design strategies of packaging suppliers and creating eco-designed product portfolio.

Ferrer has committed to reducing packaging-related carbon footprint by 25% by 2030 and 50% of our products to be eco-designed by 2030. In this regard, Ferrer has applied Life Cycle Assessment methodology to evaluate the environmental performance of their packaging. For instance, Ferrer performed an LCA of the packaging of Trinomia®, a polypill that has been developed by Ferrer Internacional S.A and the National Center for Cardiovascular Research. It is used as a complete cardiovascular treatment for the secondary prevention of cardiovascular events. The use of this polypill simplifies therapy by reducing the number of tablets to be ingested by the patient and improves both outcomes and adherence to treatment in patients whose secondary prevention is recommended. The study found that considering Trinomia® 28 presentation, the environmental impact of Trinomia® is lower than that of the equivalent treatment by 43% on average for all the impact categories considered because the amount of packaging used in Trinomia® is lower than that of equivalent treatment.

Towards a novel circularity indicator for building flooring: A comparative analysis

Pouya Samani, Lisanne Heemskerk

Netherlands Organization for Applied Scientific Research (TNO)

The circular economy has become a cornerstone of environmental policies, with the European Commission adopting the Circular Economy Action Plan (CEAP). Despite growing interest in circularity strategies, questions remain about their measurable impact and the development of effective assessment indicators. Current methodologies face challenges in comprehensively evaluating circularity across scales, from micro to macro levels. This paper aims to evaluate different circularity indicators for various flooring systems. In the flooring sector, where only 5% of materials are recycled in the EU, significant contributions are made to construction and demolition waste (CDW), which accounts for over one-third of all waste generated in the region. To address this issue, the study begins with a literature review of circularity indicators, followed by a comparative analysis of the most relevant indicators applied to three distinct flooring types. Through this analysis, the study identifies the strengths and limitations of each indicator, highlighting strategies that effectively enhance flooring circularity. Additionally, it examines barriers to achieving circularity and identifies neutral factors that do not influence circularity outcomes as measured by these indicators. The findings highlight: 1) the specific strengths and weaknesses of the studied circularity indicators, 2) alignments and gaps between circularity assessment and sustainability assessment methods such as Life Cycle Assessment (LCA), and 3) key influential factors critical for optimizing circularity indicators in the evaluation of flooring systems.

Life Cycle Assessment of Retrofitting Switchgears in Medium and Low Voltage Applications

Mariana Gaspar Martinez, Tanvi Sharma, Amelie Fehm

Siemens AG, Germany

This project evaluates the environmental impact of retrofitting medium-voltage (MV) and low-voltage (LV) switchgears through a comprehensive Life Cycle Assessment (LCA). The assessment captures both the hardware components of the retrofit kits and the service aspects, including the environmental footprint of personnel traveling to project sites for installation.

The hardware LCA focuses on materials and manufacturing impacts of the retrofit kits, which replace key components of aging switchgear systems to improve safety, reliability, and efficiency while extending the equipment's operational lifespan. The service LCA quantifies the emissions and energy use associated with on-site retrofit activities, including transportation, tools, and workforce mobilization.

By combining hardware and service LCAs, the project delivers a holistic understanding of the environmental benefits of retrofitting versus full system replacement. Results demonstrate that retrofitting offers significant reductions in material consumption, greenhouse gas emissions, and overall environmental impact. The findings highlight the importance of considering both physical and service-related contributions in LCAs for complex engineering projects, providing a model for sustainable upgrades in electrical infrastructure.

Sustainability and Performance through Life Cycle Innovation

Catarina Faria[1], Bruno Silva[1], Pedro Sá[2], Ângela Rodrigues[3,4], Gonçalo Valinho[3,4], Luís Capela[3,4], António Pontes[3,4], Luís Silva[1], Natália Ladeira[1], Bruna Machado[1]

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Portugal is Europe's largest bicycle manufacturer. However, essential cycling accessories are still predominantly imported, mainly from Asia, due to cost-effectiveness, high-quality products, and the interconnected nature of the global bicycle industry. While this reliance allows Portuguese companies to focus on assembly, design, and exports, what is the true impact of this dependency on the economy, environment, and long-term industry strategy? Polisport, a Portuguese company specialising in two-wheeled sports, seeks to reduce its dependence on imports by producing lightweight, high-performance, and sustainable products using Additive Manufacturing (AM) processes for small-scale productions. Through the INOV.AM Agenda, the company collaborates with academia to develop a sustainability-focused methodology that integrates Life Cycle Assessment (LCA) into decision-making while advancing novel AM products.

This study targets three products: a metal component, a helmet, and padding. Sustainability is prioritised through design strategies to enhance recyclability, minimise stock needs, and promote local manufacturing. Digital tools optimise mass and performance, while a decision-making matrix evaluates durability, cost, environmental impact, and overall product performance. The methodology integrates LCA and Environmental Life Cycle Costing (eLCC) to compare project-developed products' environmental and economic impacts with the baseline existing market options. LCA and eLCC methodologies were performed according to ISO 14040-44 standards. The eLCC analysis included internal and external costs, with external costs related to environmental impacts calculated using the conversion factors from CE Delft Environmental Prices Handbook 2024: EU version.

By validating sustainability through life cycle impact studies, this approach provides valuable insights for future applications across industries, driving innovation in sustainable product development.

Acknowledgement - This work is carried out within the framework of the "Agendas para a Inovação Empre-

sarial" [Project nº 49, acronym "INOV.AM"], supported by the RRP - Recovery and Resilience Plan and by the European Funds NextGeneration EU. http://www.recuperarportugal.gov.pt

Pre-emptive life cycle management for resource circulation applying a superstructure-based approach

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Emerging technologies, characterized by their rapid innovation and evolution, require advanced design and optimization processes that integrate with social systems. Although these technologies have transformative potential for material flows and life cycles, their uncertain development trajectories and sociotechnical regimes—such as regulatory frameworks, societal infrastructure, and market conditions—present significant management challenges.

A significant design issue involves evaluating multiple technologies simultaneously for a single objective. Often, the boundaries and synergies among these technologies are not adequately assessed, complicating decision-making. Superstructures in process systems engineering address this by visualizing alternative design options, enabling systematic feasibility comparisons.

This study emphasizes preemptive life cycle design to address societal challenges through emerging technologies. Case studies on battery chemicals, plastics, and regional resources underscore the importance of stakeholder collaboration and consensus-building. Superstructures were developed and employed in the communication with industries and Japanese national projects to create frameworks for evaluating technological alternatives. These were followed by life cycle assessments (LCA) to simulate impacts.

Battery chemistry challenges include optimizing recycling systems for technologies like nickel-manganese-cobalt (NMC) and lithium iron phosphate (LFP) batteries. Superstructures helped evaluate these technologies and develop scenarios for resource circulation, emphasizing strategic scenario planning for future regulatory and resource considerations.

In plastics management, systems integrating biomass-derived and recycled carbon sources were explored using superstructure models, LCA, and scenario planning. Findings were shared with stakeholders to align visions for sustainable resource circulation.

Regional resource management focused on implementing multiple technologies with strong community engagement through demonstration tests, highlighting the role of local collaboration in adoption.

These case studies demonstrate the value of superstructures in fostering a shared understanding of emerging technologies and their trade-offs. Pre-emptive LCM must address sociotechnical and socioeconomic factors in planning, using advanced computer-aided tools to ensure socially and economically viable outcomes.

Circularity in the tissue paper industry: a review of Life Cycle Assessment application to tissue paper products

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Manufacturing of tissue paper products, such as toilet paper or paper towels, has several key differences compared to production of other paper types like writing paper or cardboard. These differences, due to distinct end uses and desired properties, may result in different environmental performances. Tissue paper is indeed often made using a higher proportion of virgin pulp to achieve the desired softness and quality, potentially causing higher pressure on forest resources. Further processing required for softer and whiter tissue paper might increase water and energy consumption, while contamination issues in the End-of-Life limit the possibility of recycling and the potential benefits from recirculation of materials and resources. Circular economy (CE) strategies, such as recycling, might be of minor importance for tissue paper products.

This study, funded by the European Union - NextGenerationEU, in the framework of the GRINS -Growing Resilient, INclusive and Sustainable project (GRINS PE00000018 – CUP J53C22003140001), reviews existing literature applying LCA to tissue paper products with the aim to identify i) the environmental impacts and hotspots of tissue paper production, ii) prominent CE features, and iii) the best performing material circularity practices within the tissue paper industry. The review intends to provide an overview of the status of LCA applied to tissue paper addressing CE aspects and to identify research needs to improve circularity and its assessment within the sector.

We found that research specific to tissue paper is rather limited. Reviewed studies could be classified according to the CE principles aimed at narrowing, slowing, closing and regenerating resource flows. Addressed circularity aspects and methodological choices include: waste paper recycling and modelling of recycled content, water and energy use reduction during manufacturing, use of renewable energy sources, strategies for reduction of paper consumption. Key recommendations are provided for the implementation of material circularity practices within the sector.

Session 1.02: Future-Proof Verification processes in LCA

Time: Wednesday, 10/Sept/2025: 9:35am - 11:05am
Session Chair: Alexander Forell, Makersite, Germany
Session Chair: Gabriella Arcese, Niccolò Cusano University, Italy, Italy

Towards artificial intelligence enabled frameworks to improve critical review control and EPD verification process

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This working paper explores the adoption of new technologies to improve consistent and reliable verification of environmental performance indicators of products and services. LCA critical review (CR) for EPD verification aimed at providing reliable information on environmental performance of products and service. There is a need of improving accuracy, facilitating comparability of results between EPDs, as well as ensure impartiality and transparency of the process.

Using Artificial intelligence (AI) and machine learning (ML) for auditing EPD verification processes, can establish an effective framework for EPD Program Operators (PO) to validate the work of verifiers, improve the quality of EPDs and promote continues improvement and timesaving in the new era of massive EPD publication.

AI and ML tools offer the ability to leverage vast datasets and address complex, multidimensional issues in LCA projects. These technologies can validate LCI data by identifying, isolating, and rectifying errors, inconsistencies, and outliers, as demonstrated in numerous case studies. Algorithms can also support the auditing of the critical review (CR) process, correcting mistakes and preventing distortions by minimizing the risk of human error. The ML framework, aligned with ISO 14071 and ISO 17029 standards, enhances direct and efficient oversight of verifiers, maintaining the impartiality of the process and further reducing the potential for human mistakes. This integration not only improves accuracy but also streamlines the verification process, offering a more reliable and objective assessment of environmental performance.

Furthermore, the paper emphasizes the necessity for POs to integrate these new tools to keep pace with emerging trends and future challenges, making EPDs remain effective and relevant.

How Schneider Electric aims at Streamlining Product-Level EPD through Tool Verification and Data Governance

William Lepercq, Benjamin Canaguier, Manel Sansa

Schneider Electric

As environmental product declarations (EPDs) become increasingly critical in advancing sustainability and meeting regulatory requirements such as the Construction Products Regulation (CPR), Schneider Electric is undertaking a transformative project to transition to product-level EPD generation. This initiative streamlines EPD verification by leveraging tool validation frameworks and periodic spot verifications, ensuring scalability while adhering to standards like EN 15804+A2.

A key challenge is managing diverse input data sources, including automated and manual entries. This requires the establishment of a robust data architecture, a well-defined data model, and rigorous quality assurance processes to validate data accuracy and consistency. Comprehensive data governance protocols

ensure that input data integrity is preserved and EPD outputs remain reliable.

Schneider Electric collaborates with external partners—including industry bodies, manufacturers, verifiers, and EPD program operators—to align practices and foster interoperability. By integrating tools with pre-verified elements, automating validation checks, and rigorously governing manual input processes, the company enhances EPD generation's transparency, efficiency, and credibility.

This case study illustrates how innovative approaches to tool validation and multi-stakeholder engagement can enable scalable and reliable EPD production at the product level

Streamlining the verification process to enable more specific product footprints

Sophie Kieselbach, Alexander Forell

Makersite, Germany

The verification process in Life Cycle Assessment (LCA) represents a significant bottleneck, impeding the timely publication of LCA and carbon footprint studies. The main problem is that there are too few verifiers, and the standards are not equipped to suit scale-up or the needed amount of verifications. This challenge is exacerbated by the exponential growth in the number of studies requiring verification, juxtaposed against a relatively small pool of qualified LCA experts.

For now, it is acceptable to work with average products, and this is legitimate. However, if you conduct 1,000 LCAs that are more exact, then each one needs to be verified, which is counterindicative. The complexity of existing rulebooks governing verification and review processes further compounds this issue, creating barriers to efficient and scalable verification practices. In response to these challenges, Makersite proposes an innovative approach to LCA verification.

By leveraging advanced tools and technologies, Makersite aims to streamline the verification process, thereby enabling a scale-up in the number of experts capable of performing verifications. This novel methodology not only addresses the current shortage of verifiers but also simplifies the verification process, making it more accessible and manageable. The proposed solution holds the potential to significantly enhance the efficiency and scalability of LCA verifications, ultimately supporting the broader adoption and publication of LCA and carbon footprint studies.

Verification of AI based dynamic mapping – challenges, cases and potential guidelines.

Marten Stock[1], Matthias Schulz[2]

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The scaling and automation of LCAs is not without its challenges, particularly in the precise selection of generic information to accurately represent components listed in the Bill of Materials (BoM) for a large number of products.

In addition to deploying a robust IT-based automation solution, establishing a dependable quality assurance framework is crucial, especially considering the extensive volume of assessments conducted with minimal manual expert intervention. A comprehensive and scalable verification methodology, potentially augmented by digital or AI technologies, is essential to ensure compliance with standards such as ISO 14040/44 and others.

Our discussion bifurcates into two principal scenarios encountered in the automation of LCAs: Static Mapping and Dynamic Mapping. Static Mapping entails the creation of a master material list that facilitates one-time dataset identification and manual matching. This method faces limitations due to the presumption of a universally applicable master-material list, an assumption often invalidated in practice. Conversely,

Dynamic Mapping addresses the uniqueness of each BoM, necessitating an automated approach to map datasets and/or data models based on a variety of BoM entry-related information.

The focus of this presentation is on quality assurance and verification process of these mapping endeavorsWe explore the multifaceted challenges of verifying mapping results, including strategies for effective documentation, the establishment of quality indicators, the cultivation of trust in the mapping process among reviewers, and the critical evaluation of whether the review should concentrate on the algorithms or the results they produce.

Through the lens of practical use cases and examples, this presentation not only sheds light on the current verification challenges within LCA automation but also proposes a forward-looking discussion on necessary future advancements. Our goal is to highlight potential steps towards improving the verification process, ultimately enhancing the accuracy, reliability, and applicability of automated LCAs, thereby promoting more sustainable practices across various industries.

Framework for Verification of Environmental Product Declarations (EPDs) in Light of New Regulatory Requirements

Robert Spang

ECO Platform

Regulatory changes require life cycle assessments (LCAs) for millions of products, leading to a rise in Environmental Product Declarations (EPDs) and specialized software tools. This necessitates updating ECO Platform tool verification guidelines to ensure consistent and reliable verification. Streamlining verification while maintaining standards compliance is key, but standardizing “tool verification” is complex due to tool diversity and LCA complexity. The updated ECO Platform tool verification guidelines can be applied to any new or existing LCA or EPD tool, and includes detailed guidance to ensure EN15804+A2 and PCR conformity.

Holcim’s journey to transparent environmental communication via scalable verification processes

Andrea Charrier, Fulei Zhou, Asfand Yar Munir, Inès Aeply, Nikolaos Vlasopoulos, Vasiliki Aravani

Holcim Innovation Center, France

Environmental Product Declarations (EPDs) are third-party verified documents that are essential to communicate the environmental performance of products within the construction industry. EPDs are now transitioning from a voluntary framework to a regulatory one with the new Construction Products Regulation (CPR) that will impact over 400k manufacturers in Europe.

Until 2021, the generation of EPDs within Holcim was done “traditionally”, with the publication of one EPD during each verification process. The process was not scalable: it is lengthy, the unit cost of EPD is high and the creation of an additional EPD requires the repetition of the process from the beginning.

In 2021, Holcim decided to partner with software company Climate Earth and program operator IBU to achieve on demand EPD generators for its core businesses (cement and ready-mix concrete - RMX) across the world. The key difference between the traditional approach and the innovative one is that the focus is shifted to the set-up of whole plants and product portfolios instead of building one-off EPDs for individual products. The verification process consists in the upstream verification of the software and plant primary data, i.e. the two key components of the EPD generator. When the EPD generators are verified in each country the local Holcim teams can generate EPDs for cement and RMX concrete products within minutes.

The presentation will share Holcim’s journey to EPD automation. In particular, it will focus on the reasons

why EPD generators are better suited to automating EPD verification compared to individual EPDs. It will also cover additional ways to facilitate EPD verification through the connection of EPD generators to production and quality control software, as well as the development of EPD business intelligence services that can facilitate the use of EPDs in downstream EPD generation and verification.

Ontologies and knowledge graph for semi-automated verification of GHG assessments

Daniel Josef Lachat[1], Alexander Kirsten[1], Joana Morgado[1], Jan Grau[2], Kimberley Garcia[2], Didier Beloin-Saint-Pierre[1]

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Organisations that report on Greenhouse Gas (GHG) emissions of their value chains are facing increasing challenges to deal with a growing number of assessment standards (e.g. GHG Protocol) and many carbon footprint data sources (e.g. ecoinvent). In this context, dashboard services (e.g. Microsoft Sustainability Manager) provide support for data management and inventory compilation. Nevertheless, a key challenge remains in the diversity of requirements stated by GHG assessment standards, which might not be respected by available data sources. This leads to a need for 3rd party verification from experts to ensure that GHG assessments are valid for the selected standard, which is a time-consuming activity that can be done by a small group of people who will have to deal with numerous GHG assessments in the future.

We propose to extend existing work from the WISER project on an ontology of carbon footprint data sources with a corresponding ontology of GHG assessment standards to tackle this workload issue. Our novel ontology for standards details the key concepts that are commonly found in assessment standards and supports the verification of consistency between the used data and the rules of a standard.

We will show how the combination of the two ontologies for GHG assessment standards and carbon footprint data sources allows semi-automated creation of GHG assessments that respect the rules of various standards. The operational implementation of these two ontologies, in the form of two knowledge graphs, is the key to enable semi-automated verification, thus helping experts during their review process. We will also show how the information from the knowledge graphs can be used in dashboard services.

Finally, an outlook will be given on further extensions of the knowledge graphs to tackle additional tasks for comparability evaluation and how the knowledge graphs could be used with the Life Cycle Assessment method.

Corporate Data in PCF Calculations: Methodological Challenges and Opportunities

Lisa Rasmusson, Elias Hallack, Mats Berglund, Annica Isebäck

AB SKF, Sweden

The demand for greenhouse gas (GHG) emissions data is increasing due to stakeholder expectations and legal requirements such as the EU's Carbon Border Adjustment Mechanism (CBAM) and the Corporate Sustainability Reporting Directive (CSRD). Data collection follows different standards depending on whether it is for product-level calculations such as Product Carbon Footprint (PCF) according to ISO 14067 or corporate-level calculations such as GHG inventory according to the GHG Protocol Corporate Standard (GHGPCS). Collected data is also used for other purposes, such as energy efficiency improvements and in purchasing. As data sources and methods significantly impact results, using varied approaches between studies complicates data verification, leading to higher risk of model discrepancies and variations in results.

To address these challenges, SKF has been investigating the possibility to utilize data from its GHG inven-

tory to enhance reproducibility and transparency in PCF calculations. Over the past few years, SKF has used its GHG inventory data collected according to the GHGPCS to calculate average emission estimates on SKF products. Recently, SKF has advanced this approach by integrating the GHG inventory data into PCF calculations according to ISO 14067. SKF is currently investigating standardizing these calculations, enabling methodology and data consistency.

In this presentation, the journey of this approach will be shared. The methodological challenges will be discussed, such as handling data quality requirements and allocation approaches, and how they are addressed. The strengths of this approach will also be highlighted, including the broad implementation of the GHGPCS at suppliers. This increases the efficiency to calculate PCFs, enabling a new scale of data analysis and result interpretation.

The presentation will conclude that using this approach streamlines data verification efforts within a company, but also that increased alignment between the standards is needed to fully realize the potential of the cross-over data collection between standards.

Prospectool, a novel software platform that leverages prospective Life Cycle Assessment LCA to guide eco-design

Tom van Schaijk, Roel Degens, Gustavo Ezequiel Martinez, Gabriela Espadas Aldana, Javier Yélamo Mayorga, Giuseppe Cardellini

VITO, Belgium

As sustainability pressures intensify, decision-makers and product developers increasingly seek methods to proactively design for reduced environmental impacts. Traditional LCA approaches, grounded in static and retrospective analyses, provide limited insights for shaping future-oriented ecodesign strategies. To bridge this gap, Prospectool is presented, a novel software platform that leverages prospective LCA to guide ecodesign by incorporating dynamic, forward-looking parameters and uncertainty into the environmental evaluation process.

Prospectool enables practitioners to model emerging technologies, materials, and supply chains under evolving conditions. By integrating scenario analysis, sensitivity assessments, and predictive modelling, the software highlights how design decisions made early in product development can influence long-term sustainability performance. Its flexible architecture ensures smooth interoperability with existing LCA databases while allowing continuous integration of updated data as new innovations and environmental parameters emerge.

Crucially, Prospectool empowers ecodesign by allowing designers, engineers, and sustainability teams to explore multiple technology pathways before committing to specific solutions. Users can systematically evaluate trade-offs across different environmental indicators, revealing strategies to minimize resource consumption, greenhouse gas emissions, and other environmental burdens across the product's expected life cycle. This forward-looking perspective ensures that ecodesign is not merely reactive to current constraints but anticipates and adapts to future changes in technology and policy landscapes.

This presentation will introduce Prospectool's methodological foundations, demonstrate key functionalities through representative case studies, and discuss validation efforts. Prospectool facilitates a crucial shift from reactive to proactive life cycle management. By enabling forward-thinking eco-design, it helps create products that are resilient to future changes in technology and policy, driving long-term sustainability goals.

Session 1.03: Pathways to Net-Zero: Industrial Decarbonization & Green Energy Part I

Time: Wednesday, 10/Sept/2025: 9:35am - 11:05am
Session Chair: Nele De Belie, Ghent University, Belgium
Session Chair: Pascal Di Croce, EuLA, Belgium

Decarbonizing the aviation sector: A detailed LCA model for exploration of methanol-based Sustainable Aviation Fuel production and its scaling up while decarbonizing other sectors

Karin Treyer, Christian Moretti

Paul Scherrer Institute, Switzerland

The aviation sector is responsible for approximately 3% of global direct CO_2 emissions. However, its overall impact on climate change and the environment is greater due to supply chains and non-CO_2 effects. The European Commission has established mandatory volume blending goals for Sustainable Aviation Fuels (SAF), starting at 2% in 2025 and increasing to 63% by 2050. Half of this mandate shall be met with bio-SAF derived from biomass feedstock, while the remaining 50% must be achieved with synthetic SAF (sSAF), produced using hydrogen (H2), carbon dioxide (CO_2), and electricity from renewable sources.

This presentation will introduce our LCA model for the production of SAF from methanol (MeOH). MeOH and its feedstocks - H_2 and CO_2 - are already critical substances in the chemical industry, but their current production is predominantly fossil-based. As the sector works to decarbonize, it must simultaneously expand its capacity to meet growing demands, including those of the aviation industry. Our research aims to evaluate the greenhouse gas (GHG) emissions reduction potential of this SAF production pathway (which must achieve a minimum 10% reduction to qualify as SAF). Beyond GHG emissions, we also assess other environmental impacts and non-CO_2 climate change impacts.

To achieve these goals, we have developed a model that explores a wide range of potential supply chains for H_2, CO_2, and MeOH, with particular focus on temporal and geographical considerations: Where should production, storage, and transportation of these substances take place? Can industrial processes be co-located to optimize resource use, for instance by using excess reaction heat for CO_2 capture? Furthermore, can the production of H2, CO_2 and renewable electricity be scaled up sufficiently to support sSAF production, without conflicting with the decarbonization goals of other industries?

Pathways for the global chemical industry to climate neutrality

Ronja Hermanns[1], Oskar Vögler[1], Stefano Zehnder[2], Cassia Oliveira de Lima[2], James Wilson[2], Raoul Meys[1,3]

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The International Council of Chemical Associations (ICCA), representing chemical manufacturers and producer that account for more than 90 percent of global sales, published a climate neutrality statement in 2021. To reach its ambitions, ICCA has commissioned a study to identify climate-neutral pathways and key enablers for the global chemical industry. Although climate neutrality studies exist, there is still no science-based climate neutrality study that has been conducted in consultation with almost all chemical industry associations. This missing study highlights a gap in the interactions between industry and science.

To fill this gap, we include industry expert knowledge from almost all chemical associations in a peer-reviewed modelling approach based on life cycle assessment (LCA). This LCA model can be used to support

industrial decarbonization decision-making by determining cost-optimal technology choices for a climate-neutral chemical industry.

For this, our climate neutrality study covers the current and prognosed production of 18 high-volume chemicals and plastics considering electrification, bio-based technologies, carbon capture, utilization and storage, and renewable energies. Besides the technologies, the model defines scenarios with low and high availability of critical resources based on industry expert knowledge, such as biomass and carbon capture and storage capacities. These scenarios show that multiple pathways to achieve climate neutrality exist. The climate-neutral pathways highlight alternative technologies such as recycling technologies, fossil feedstocks with carbon capture and storage, and bio-based technologies that are leading to comparable lower costs.

Decision-makers in policy and industry can use this industry- and science-based study to foster these lower-cost technologies by expanding and securing the availability of key enablers, such as sorted plastic waste, sustainably sourced biomass, fossil feedstocks and adequately regulated carbon storage, and affordable low-emission energy.

Nature-based solutions toward net-zero: surface albedo matters ! Demonstration on the case of carbon credits

Maëlys David[1,2], Kathryn Loog[1], Anne de Bortoli[1,3,4], François Saunier[1]

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The IPCC's scenarios compliant with the Paris agreement heavily rely on the deployment of technological or nature-based carbon capture systems. The greenhouse gas (GHG) removed by these systems can either be used by their owner directly (= in-setting) or traded (= offsetting) via carbon credits. Recent studies estimate low mitigation efficiency of carbon credits (0-25%) depending on the type of carbon capture project. While many nations strongly count on the conversion of lands to forests or energy crops to reach net-zero, the climate impacts of the resulting modification of the surface albedo are not accounted for in these policies' assessment, which may jeopardize climate targets. In particular, the credits issued by afforestation, reforestation or revegetation (ARR) projects do not consider the impact of surface albedo changes in the quantification of net GHG removal. To assess the complete impact of ARR projects, including albedo effects, we considered 100 ARR projects from VERRA's "Verified Carbon Standard", the main carbon crediting program. We extracted the data from the public documentation of each project, including both written project descriptions and geospatial datasets, for which ~70% of the projects had the required information available. We calculated the difference in albedo between the baseline and the project activity land uses (i.e. without and with the project), considering project-specific tree types, planted parcels, and location-based albedo values computed using NASA MODIS satellite data. We then calculated the radiative forcing in CO2 equivalent for the project area over the crediting period. Finally, we compared the results with the reported carbon credit estimates: on average the impact of surface albedo change offsets 11% of the benefits predicted and for 56% of the projects the volume of carbon credits issued should be reduced by 5 to 273%. We conclude with recommendations for updating carbon quantification methodologies and selecting carbon credit projects.

Using Marginal Abatement Cost and carbon Curves to support decision making toward net zero emissions

Benjamin Canaguier[1], Jean-Pierre Schweitzer[1], Jeanne Briand[2], Baptiste Pécresse[2], Baptiste Sene[2], Svilen Iskrov[2]

[1]Schneider Electric; [2]Accenture

Most of public and private organisations are committing to reduce drastically their Scope 3 carbon emissions in order to reach Net-Zero emissions across their full value chain (e.g. SBTi validated targets). Critically, these emissions pertain to activities not in an organisations direct control and therefore require careful coordination with suppliers and customers. Furthermore, the economics and effectiveness of different abatement strategies are not uniform. Marginal abatement cost curves (MACC) are a widely used tool to aid decision making when it comes to prioritising decarbonisation (or other depollution) levers according to their cost-effectiveness. In the case of green house gas (GHG) emissions, the marginal abatement cost of carbon describes the cost related to removing the last unit of emissions to meet a target by a specified date. Schneider Electric and Accenture have developed commodity specific MACC for Steel, Aluminium, Copper and Plastics integrating multiple macro-economic scenarios and a comprehensive list of carbon abatement technologies (Hydrogen, Carbon Capture and Storage, Circular Business models…). MACC models were adapted to product design in order to identify Life Cycle Principles to drive both R&D and Procurement. Additionally, the exercise was not limited to carbon, since other Life Cycle Impact Assessment indicators were used to identify potential tradeoffs.

How can Carbon Dioxide Removals (CDRs) contribute to achieving Net-Zero emissions

Hanne Lerche Raadal, Ingunn Saur Modahl

NORSUS, Norway

IPCC's Sixth Assessment Report (IPCC, 2023) defines carbon dioxide removal (CDR) as: "Anthropogenic activities removing carbon dioxide (CO2) from the atmosphere and durably storing it in geological, terrestrial, or ocean reservoirs, or in products. It includes existing and potential anthropogenic enhancement of biological or geochemical CO2 sinks and direct air carbon dioxide capture and storage (DACCS) but excludes natural CO2 uptake not directly caused by human activities." Hence, negative emissions can only occur when CO2 is taken from a biogenic point source (or by direct air capture) and sequestered, which is also in line with EU's Carbon Removal Certification Framework (CRCF).

In general, LCA methodology is recommended for calculating CDRs to assess whether the technology deliver net negative emissions over the value chain. The system boundaries, defining what is included and not are important. These can be spatial (e.g., considering only impacts within a specific country), temporal (for a defined time span), and technological (only certain infrastructure systems are included). A harmonised methodology for quantifying net CO2 removal is therefore crucial for the development of a trusted CDR industry (Nordahl et al., 2024).

Net negative emissions (CDRs) for a BECCS value chain utilizing waste resources as feedstock for a waste-to-energy (WtE) plant with CCS will be presented. The results are derived from LCA methodology, employing various system boundaries (e.g., including waste transport to the WtE plant) and allocation methods (e.g., attributing all fossil emissions to the stored biogenic CO_2). The presentation will also address the difference between avoided and negative emissions and counterfactual scenarios for treatment of the incinerated waste. Finally, a discussion will be presented on the relevance of the results for both voluntary and regulatory carbon accounting frameworks, with a focus on their potential contribution to achieving Net-Zero emissions.

*BECCS: Bioenergy with Carbon Capture and Storage

Environmental and resource use analysis of chemical sugar synthesis for biomanufacturing

Hiro Tabata[1,2], Satoshi Ohara[1], Yuichiro Kanematsu[1], Heng Yi Teah[1], Yasunori Kikuchi[1]

[1]The University of Tokyo; [2]The University of Osaka

Sugars such as glucose and fructose are fundamental substances that underpin human food production and serve as crucial substrates in the bioproduction of chemicals. Currently, sugars are produced through photosynthesis (i.e., agriculture) using water and CO_2 as raw materials. However, the current sugar production volume is insufficient to meet the enormous demand for fuels and chemicals. Excessive expansion of sugar use in biomanufacturing risks creating competition with food production. Against this background, there has been growing interest in catalytic chemical sugar synthesis as an alternative production method. This approach is expected to result in significantly faster production speeds, on-site production, and a substantial reduction in the use of resources such as land and water, compared to conventional agricultural sugar production. As a result, it is anticipated to address the challenges associated with raw material supply in bioproduction. In this study, the energy requirements and environmental impacts of each process were evaluated using life cycle assessment (LCA).

The results confirmed that the catalytic chemical sugar synthesis could significantly reduce environmental impacts such as land use and eutrophication compared to agricultural processes, as initially hypothesized. On the other hand, because the catalytic process requires more energy than agricultural processes, it was found that improving carbon yield through the introduction of recycling mechanisms and decarbonizing power sources are essential for reducing greenhouse gas emissions.

This study quantitatively demonstrates the societal significance of supplementing the sugar supply for biomanufacturing through chemical synthesis processes. It is expected to provide a new option for raw material supply in biomanufacturing and contribute to the broader carbon resource circulation system, including food production.

A prospective environmental and economic analysis to pave the German hydrogen transformation path to 2030 and 2045

Mélanie Apitzsch-Delavault[1,2], Maike-Katharina Senk[2], Holger Jorschick[3], Mario Schmidt[2]

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Hydrogen has a major role to play in meeting the german's goal of carbon neutrality in 2045(IEA - International Energy Agency). Emerging technologies could offer a great opportunity to reduce the environmental impact of hydrogen production and to lower production costs. Our study aims to quantify the environmental impacts of emerging technologies, combine the environmental results with an economic analysis and recommend transformation pathway for decision makers.

Prospective life cycle assesments from emerging technologies are performed to calculate the environmental impact of hydrogen production. The annuity method is used to calculate the Levelized Cost of Hydrogen (LCOH). The following scenarios, which consider emerging technologies, are evaluated: an inland production scenario in Germany using electrolysis, as well as an import scenario using hydrogen derivatives.

By 2030 the results of the global warming potential show that the available electrolysis technologies lead to a possible reduction of more than 50% of greenhouse gas (GHG)-emissions compared to the reference process, while the economic results shows a cost increase of 150%. By 2045 the hydrogen derivatives Liquid Organic Hydrogen Carriers (LOHC) and ammonia combined with the electrolysis, could present an interesting alternative to the reference process, reducing GHG-emissions by more than 80%, while the costs of hydrogen derivates, electrolysis, and the reference process are equivalent. The recommended pathway is to first produce hydrogen via electrolysis in Germany, and by 2045, to combine the electrolysis in Germany

with the import of hydrogen derivatives.

Our overview demonstrates that electrolysis and hydrogen derivatives could support the decarbonization of hydrogen production in Germany drastically reducing GHG-emissions althought costs would be higher in the short-term compared to the reference technology. Our findings suggest that global solutions between industry and politics are urgently needed to reduce production costs in the short-term and accelerate the transition to low-carbon hydrogen production in Germany.

Lifecycle assessment of atmospheric and industrial carbon capture using heat pumps

Ankur Dnyaneshwar Gaikwad

Fraunhofer UMSICHT, Germany

Introduction

Carbon capture features as the most important climate change mitigation measure. However, their energy intensity hinders their adoption on a larger scale. The monoethanolamine-based carbon capture technology (MEA-CC) is used to capture CO2 from industrial CO2 sources, while low-temperature direct air capture (LT-DAC) technology to capture CO2 from atmosphere is currently in development phase. They require heat input at temperatures below 150 oC. Industrially, heat input at these temperatures is provided by steam produced in natural gas or coal-fueled boilers. High-temperature heat pumps provide a cleaner alternative to boilers for such applications.

Research question

My contribution evaluates application of high-temperature heat pumps to the two carbon capture technologies. I primarily aim to identify environmental issues of significance and/or process optimization opportunities by sound application of lifecycle assessment.

Method

The two carbon capture technologies with heat pumps are evaluated first using the Environmental Footprint 3.0 impact assessment methodologies. A scenario analysis compares them to the reference case when natural gas-fueled boiler provides the heat for the respective technologies. Sensitivity analyses account for relevant parameters in the overall system. Trade-offs among the various impact categories are explored, providing insights on possible technologies to remedy the trade-offs of using heat pumps for carbon capture systems.

Results

The electricity supply influences the climate change impacts significantly. Sensitivity analyses show that heat-pump-based systems reduce GHG emissions when electricity mix has carbon footprint lower than ca. 0.76 kg-CO2-eq./kWh. With a prospective German electricity mix, trade-offs in impact categories like minerals & metals' resource use, particulate matter & freshwater ecotoxicity are observed when using heat pumps vs. natural gas. Normalized & weighted scores show reduction in overall environmental impacts when using heat pumps.

Conclusion

Lifecycle assessments provide holistic perspective on environmental impacts, benefits and trade-offs in implementing process technologies for climate change mitigation.

A Stepwise Methodological Framework for Enhancing Comparability in Life Cycle Assessment of CO_2 Adsorption in Hard-to-Abate Industries

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Carbon Capture and Storage based on CO2 adsorption technology is a promising technology and represents a critical measure for achieving decarbonisation in hard-to-abate industries. To evaluate its environmental benefits and potential burdens, Life Cycle Assessment (LCA) has been widely adopted as a consensus tool. Nevertheless, current LCA studies in this field exhibit significant methodological discrepancies, severely limiting the comparability of different studies. To address this challenge, this study systematically reviews 26 LCA studies published between 2006 and 2024 on the application of CO_2 adsorption technology in hard-to-abate industries. By referencing the latest international standards (e.g., ISO 14040), EU standards (e.g., ILCD Handbook series), and relevant guidelines (e.g., "Techno-Economic Assessment & Life Cycle Assessment Guidelines for CO_2 utilization (Version 2)"), this study identifies key methodological factors affecting comparability and proposes a three-tiered methodological framework based on implementation difficulty. The first tier requires no additional effort and focuses on improving reporting practices and quality, such as clarifying system boundary types and data quality requirements. The second tier involves minimal effort, such as conducting data quality analysis and investigating a broader range of impact categories. The third tier, being the most challenging, demands significant effort, such as significance level assessment of differences in impact category results with uncertainties, as well as context, model, and quanlity uncertainty and sensitivity analyses. This framework not only identifies key opportunities to enhance comparability but also provides a practical stepwise pathway for methodological improvement, offering clear guidance for future research.

Session 1.04: Life Cycle Metrics for industry and policymakers: From Innovation to Integration I

Time: Wednesday, 10/Sept/2025: 9:35am - 11:05am
Session Chair: Luca Zampori, PRé Sustainability, The Netherlands
Session Chair: Davis Jose, INaB - RWTH, Germany

Scaling-up life cycle thinking into corporate footprint strategy: The Electrolux Group strategy

Stefano Zuin[1], Vsevolod Dengin[2], Natalia Lopez Marin[1], Vincenzo Lariccia[1], Monica Celotto[1]

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So far, thousands of companies have committed to the ambition of net-zero carbon emissions through the science-based targets (SBTs) initiative. The Electrolux Group has recently set a new science-based climate target to reduce its direct and indirect emissions. Our overall objective is to achieve net-zero emissions throughout the value chain by 2050. As a part of this journey, we recognize there are various methodological approaches to carbon accounting and choices to be made consequently may be a challenge, especially in addressing indirect emissions due to company activities according to the GHG protocol, Scope 3. For an effective implementation, the life cycle assessment (LCA) methodology may be used for calculating carbon footprints, identifying carbon-intensive stages of a product's life cycle, and opportunities for reduction. This paper aims at sharing how LCA is used in Electrolux Group in the context of corporate footprint to provide valuable insights in understanding Scope 3 emissions, and to address aspects of consistent greenhouse gas (GHG) emissions accounting and assessment. In detail, we explain how, for supporting the calculation of GHG inventory Scope 3 Category 1 (purchase goods and services), a material footprint indicator was developed by using our LCA studies and the Ecoinvent database. A Power BI dashboard was then created as it provides a consolidated view of material footprint data and high-level insights immediately. We then describe the methodology used to calculate emissions during the use phase of sold products for the Scope 3 Category 11, with an insight concerning criticalities when using emission factors for electricity from specific databases in LCA studies and the accounting of GHG emissions. Finally, we will explore some emerging opportunities to further incorporate life cycle thinking into decision-making contexts of carbon accounting.

Applying Matrix-Based Modeling for GHG Emission Forecasting and Corporate Decarbonization Strategy Evaluation: A Steel Manufacturing Case Study

Alessandro Marson[1,2], Alessandro Manzardo[1]

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As the urgency to address climate change intensifies, organizations across sectors are compelled to adopt robust methodologies for projecting greenhouse gas (GHG) emissions and evaluating mitigation strategies. This presentation showcases the application of a novel matrix-based model through a comprehensive case study in the steel manufacturing industry, an emissions-intensive sector with significant environmental impact.

The model's 'Projection' functionality estimates emissions under a 'Business as Usual' (BaU) scenario, considering critical factors such as business volume growth projections and external context evolution, including grid decarbonization and technological advancements that influence emission factors. The 'Reduction' functionality enables organizations to simulate the effects of multi-year reduction plans, starting from the

BaU projection baseline.

In this steel manufacturing case study, the model evaluates the company's positioning relative to communicated targets and regulatory requirements. By combining multiple reduction actions from an extensive software library, the model accounts for their combined impact on the BaU projection, considering potential synergies or conflicts between different initiatives. This approach empowers organizations to accurately simulate the effects of planned reduction initiatives, facilitating informed decision-making, optimizing strategies, allocating resources effectively, and aligning efforts with both internal targets and external stakeholder commitments.

Key insights demonstrated through the case study include integrating business growth projections and external context factors for robust BaU emissions forecasting, evaluating positioning against targets through simulated reduction plan scenarios, and accounting for synergies or conflicts between various reduction actions. Additionally, the presentation highlights the model's capabilities in navigating the complexities of industrial emission portfolios, particularly in emissions-intensive sectors like steel manufacturing. Through this real-world application, the presentation underscores the model's potential to drive meaningful decarbonization in industrial sectors, addressing a critical need as organizations pursue increasingly ambitious climate strategies.

Proposal of scalable biodiversity footprint assessment framework for cosmetic products based on state-of-the-art methodologies

Jacques L'Haridon[1], Magdalena Czyrnek-Delêtre[2], Laurine Mourichou[1], Jad Zoghaïb[1], Anne-Claire Asselin[3]

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Today, within the sustainability program "L'Oréal For The Future", ambitious commitments have been set by the company to continue tackling environmental issues. The tool to support product developers in contributing to these commitments is SPOT (Sustainable Product Optimization Tool), an eco-design tool for cosmetic products based on life cycle assessment (LCA). As the science around biodiversity impact continues to progress, it is essential for L'Oréal to develop an understanding of the biodiversity footprint at product level to support eco-design with aim of the preservation of biodiversity as well as to explore how it connects to commitments at corporate level.

In order to leverage the already acquired knowledge and available life cycle data, the LCA-based approaches have been prioritized for building a relevant in-house Product Biodiversity Footprint Assessment framework for Cosmetics (PBFA-C). This PBFA-C built on state-of-the-art methodologies suggests the use of (i) the SPOT method for a first screening level of insights and (ii) additional known life cycle impact assessment methods applied in biodiversity footprint studies to provide more specific results when needed.

This work will enable to formulate recommendations for internal implementation and deployment of PBFA-C at different scales:

• Screening studies, with key data and hypotheses, which could be applied to the entire L'Oréal product portfolio as well as innovation projects at different life cycle stages (e.g. sourcing of raw materials, production of formula ingredients, end-of-life of products, etc.),

• Standard studies, with more refined and accurate data, applied to some products,

• Complete studies, with data and hypotheses of high quality for a potential confirmation of results obtained in a screening or standard study.

Results of case studies as well as a brief discussion on the articulation of this approach with the corporate biodiversity footprint metrics will be presented to highlight the relevance of the proposed PBFA-C.

Consensus building for a European-wide harmonized life cycle assessment approach for a zero-emission road transport system: Results of the TranSensus LCA project

Takunda Yeukai Chitaka, Guido Sonnemann

University of Bordeaux, CNRS, Bordeaux INP, ISM, Bordeaux, France

The transport sector is a major contributor to global greenhouse gas emissions. As a result, our road transport system is rapidly transforming with zero-emission propulsion systems achieving steadily increasing market shares. However, in order to define realistic sustainability goals – for all stakeholders in the mobility sector – and to select the most sustainable solutions, the environmental, economic and social impact of technologies and mobility concepts must be assessed and continuously monitored in a holistic way. This presents a need for a harmonised assessment approach for zero-emission transport systems to ensure consistency and comparability.

TranSensus Life Cycle Assessment (LCA) is a coordination and support action project funded by the European Union. It aims to pave the way towards a commonly accepted and applied single LCA approach for the LCA of zero-emission road transport systems in Europe. This is done through a consensus building approach which engages the consortium, associated partners, defined scientific and industry advisory boards as well as the wider stakeholder community including the European commission, standardisation bodies and member states. In addition, TranSensus LCA investigates the applicability of the harmonized approach through road testing with industry and research partners.

After three internal votes consensus was reached on 137 methodological requirements, 56 of which being mandatory, concerning environmental and social LCAs of product, prospective and fleet LCAs. The requirements were incorporated into a guidance document outlining how to implement the TranSensus LCA methodology. Ultimately, TranSensus LCA will enable industry, mobility providers and planners to provide sustainable products and to optimise mobility solutions as needed to combat climate change.

ProScale and ProScale-E for chemical footprints in initial LCA in SSbD

Rosella Telaretti Leggieri, Pernilla Andersson, Ziye Zheng, Triranta Sircar, Maja Halling, Tomas Vilhelm Rydberg

IVL Swedish Environmental Research Institute, Sweden

The ProScale method for chemical footprint covering direct exposure related human toxicity potential was developed and established in 2016-17, onwards referred to as ProScale-H. More recently the ProScale-E method has been developed, in order to capture also environmental exposure and impacts.

Both ProScale modules (H and E), require little to moderate substance data while still providing meaningful results. A key aspect of both modules is to make use of Hazard classification according to REACH information and translate hazard classes into numerical scores from 0-100000. For new chemicals, A guidance is provided how to estimate a hazard score based on various chemicals property prediction methods, including QSARs etc.

Human exposure in ProScale-H, is based on the ECETOC TRA tool, i.e. determinants for the process type, the substance properties, protection measures and air exchange. The module can be appropriately used for initial exposure estimates for chemical processes in the design stage.

For ProScale-E environmental exposure, a first tier very simple fate scoring model has been established, based on biodegradability and persistence properties of the chemical.

The little to moderate need for data allows both models to be applied in early innovation phases.

For releases, one option is to use release factors based on Environmental Release Categories (ERCs) and Specific ERCs (SpERCs) as proposed by ECHA for environmental exposure assessment within REACH.

Other methods under investigation is backwards calculation from the ECETOC TRA exposure estimates, and estimated based on engineering design handbooks.

A very significant advantage with the ProScale indicators is that they to a very large extent are based on already implemented tools and approaches in industry dealing with chemicals safety, i.e. based on data and tools in REACH.

The presentation will display and discuss a variety of examples where the developed approaches have been tested. Advantages and challenges will be discussed.

Technology based two-step allocation approach for complex, highly integrated systems like refineries

Jan Blömer, Ankur Gaikwad, Venkat Aryan, Daniel Maga

Fraunhofer UMSICHT, Germany

In highly integrated facilities (e.g. refineries or chemical plants), where multiple intermediate and final products are produced through interconnected unit processes, the correct allocation of environmental burdens is challenging. These systems are characterized by both forward and backward flows, often forming loops that make stepwise burden allocation infeasible. Consequently, the flow matrix equations must be solved simultaneously, which is difficult or often infeasible using standard LCA software.

To address this issue, we propose a two-step allocation approach. In the first step, all burdens originating from the emissions of each unit process including the respective upstream inputs are calculated. In the second step, these unit-specific burdens are attributed to all internal and product flows as specific “backpacks”. The allocation can be performed based on mass, heating value, or price, or a combination thereof simultaneously within the same plant. Most unit processes are assumed to behave as ideally mixed vessels for the allocation of the burdens in each unit; however, other rules are possible, too.

Thus, our approach solves the simultaneous burden allocation equations very efficiently, capable of handling complex systems comprising hundreds of flows. The simultaneous equations are formulated automatically based on a given table of input-output flows for each unit process, requiring only the footprints of utilities (caused by e.g. electricity, steam, gas, water etc.) to be calculated for each unit.

The approach developed here aligns with the established refinery modeling principles (e.g. TfS), ensuring comparability of results. Unlike conventional black-box methods applied at the refinery-level, our method preserves critical process-level technological details, enhancing granularity and delivering a technology-based burden allocation.

The developed method has been validated successfully in two large European refineries, demonstrating both its robustness and practical applicability to complex, highly integrated industrial systems.

Improving Environmental Performance using a flexible LCA-based Decision-Matrix

Gerald Feichtinger, Wolfgang Posch

Chair of Economic and Business Management, Montanuniversitaet Leoben, Austria

Introduction

The entire chain of activities of companies causes direct and indirect environmental effects. Direct effects are subject to the organisation’s direct control such as emissions to air. Indirect effects, on the other hand, arise from an interrelationship between the organisation with third parties, that the company may not be able to fully control. A commonly accepted tool for analysing effects along the chain of activities are life

cycle assessments (LCAs). This paper presents a LCA-based environmental assessment matrix that can be flexibly used to optimise the environmental performance of products or entire companies.

Methodology

This assessment-matrix analyses the environmental aspects (columns) of all processes (rows) of a target object by using the Life Cycle Inventory (e.g., energy input) and the Life Cycle Impact Assessment (e.g., Global Warming Potential). All environmental aspects from the LCA are normalised using a scale between 0 (not relevant) and 3 (high relevance). A weighting score for each environmental aspect is calculated, reflecting the environmental vulnerability (local, regional, global) with a base weighting of 1 (no effect). For the processes, the influencability of the process regarding environmental impacts and the process-based optimization potential are assessed using a scale between 1 (low) and 3 (high).

Results

Firstly, the materiality of the environmental aspects of the target object is the weighted sum of priorisations of all evaluated processes. Secondly, the environmental priority of the process is the product of the weighted sum of environmental impacts, the influencability and the optimisation potential. Thirdly, a process-based priority ranking for the target object for proper decision-making.

Conclusion

This procedure ensures that significant environmental aspects are identified in time and that measures can be taken in a timely manner at both product and organisational level. Assessment categories (columns) can be exchanged flexibly (e.g., alternative LCIA methods, compliance with environmental standards).

Beyond Cradle-to-Gate: Embracing Full Life Cycle Assessment for comprehensive Eco-Design solutions

Sarah Badioli[1,2], Thibault Champion[2], Marielle Dargaud[2], Angélique Léonard[1]

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Sustainable development is key to political and strategic agendas in the current economy. The rising demand for eco-friendly products and stricter environmental regulations drive companies to conduct Life Cycle Assessments (LCA) and adopt sustainability action plans.

LCA scientifically quantifies the environmental impacts of products throughout their life cycle, hence being a powerful tool for sustainability efforts. Companies are increasingly using LCA to include environmental information in their product design as a prospective strategy, in addition to analysing current product systems retrospectively. Indeed, LCA results drive the choice of eco-design solutions, which often refer to improved durability and recyclability of products. In both cases, the intent is to distribute the impacts of the product manufacturing, reduce the per-use footprint and promote an efficient use of resources. Such a perspective requires the inclusion of the usage and, possibly, end-of-life stages in the LCA. Expanding the system boundaries raises challenges related to the allocation approach, functional unit and inventory set-up.

This study discusses the eco-design of refractory products, i.e. ceramic materials able to withstand high temperatures in harsh conditions. The cradle-to-gate and cradle-to-grave LCA of two refractory bricks intended for the same application in steel production are conducted and compared. The system and functional unit related to the usage in steelmaking are defined based on theoretical models, laboratory data on materials' thermal and corrosion performance, and real plant data on operating conditions.

Current State of LCA/LCT in Food Public Procurement

Cecilia Casonato[1], Laura Garcia Herrero[2], Esther Sanye Mengual[2], Giulia Listorti[2]

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Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA) are increasingly being used to quantify environmental impacts in food system analyses, and their application for policy support is gaining momentum. It is thus important to further explore and understand how LCT and LCA can support policies fostering the transition to more sustainable food systems. Public food procurement is recognized as a powerful demand-side market instrument that can help shape consumption and production towards increased sustainability, by encouraging the adoption of sustainable healthy diets and purchase of greener products. We conducted a comprehensive analysis to investigate the use of LCT and LCA in food public procurement, consisting of a literature review of methodological approaches and indicators used to assess sustainability, combined with qualitative assessment of existing food procurement provisions across selected EU Member States. The analysis revealed that most LCA case studies focus on a single environmental impact (such as carbon footprint) and often do not use the most updated impact assessment methods. Furthermore, LCA results are used for practical applications, such as evaluation or menu planning, but often transparency and clarity in the methodology and data used are lacking. Improved menu planning, reduction in food waste, and procurement of organic food are widely investigated, while measures such as energy efficiency of appliances and packaging reduction are less. The analysis of EU Member States' provisions shows that environmental issues are prevalent, while the socioeconomic ones are heterogeneously addressed in various hotspots, ranging from animal welfare to workers' rights.Those key actions for sustainable food procurement, such as adopting plant-based diets, are not adequately supported by practical implementation guidance. Social and economic impacts are seldom explored systematically in the analyzed literature and require further integration in sustainability assessments. Support policy design and implementation with LCA needs further harmonization and guidance to accompany stakeholders.

Session 1.05: LCA in the mining and metals industry: Current practices and challenges

Time: Wednesday, 10/Sept/2025: 9:35am - 11:05am
Session Chair: Johannes Arnold Drielsma, Drielsma Resources Europe, The Netherlands
Session Chair: Stéphanie Muller, BRGM, France

LCA of metals and minerals supply: a comprehensive analysis of global environmental impacts covering 54 elements

Frederic Lai[1], Stéphanie Muller[1], Audrey Philippe[1], Robert Istrate[2], Brenda Miranda Xicotencatl[2], Afsoon Mansouri Aski[3], Aina Mas Fons[4,1], Juliana Segura-Salazar[5], Jair Santillán Saldivar[1], Alex Cimprich[6], Stephen Northey[7], Lígia da Silva Lima[8], Lieselot Boone[8], Ryosuke Yokoi[9], Kamrul Islam[9], Ioanna Paschalidou[10], Felipe Cerdas[11,12], Victor Balboa-Espinoza[5], Anish Koyamparambath[4], Diae Hennioui[1], Victoire Collignon[1], Aurélien Reys[1], Gyslain Ngadi Sakatadi[13], Jo Dewulf[8], Bernhard Steubing[2], Christoph Helbig[3], Gaétan Lefebvre[1], Gian Andrea Blengini[14,13], Valeria Superti[15], Masaharu Motoshita[9], Guido Sonnemann[4], Kwame Awuah-Offei[10], Steven B. Young[6], Shinsuke Murakami[16], Antoine Beylot[1]

[1]BRGM, France; [2]Leiden University, Netherlands; [3]University of Bayreuth, Germany; [4]University of Bordeaux, France; [5]University of Queensland, Australia; [6]University of Waterloo, Canada; [7]University of Technology Sydney, Australia; [8]Ghent University, Belgium; [9]AIST, Japan; [10]Missouri University of Science & Technology, United States; [11]THWS, Germany; [12]Fraunhofer IST, Germany; [13]Politecnico di Torino, Italy; [14]University of Turin, Italy; [15]ecoinvent association, Switzerland; [16]University of Tokyo, Japan

LCA of metals and minerals supply often reveals varying environmental impacts (by orders of magnitude) from one study to another. This variability in impacts may stem from i) coverage of different production routes, ii) different life cycle inventory (LCI) data sources, and iii) different methodological approaches in the modelling.

To offer a better understanding of the environmental impacts of metals and minerals supply, this study aims to comprehensively assess these impacts for 54 different elements through LCA.

As a first step, this study comprehensively reviews publicly available LCI data (i.e. in literature) related to industrially established supply chains of metal and mineral commodities. This review is accompanied by a data quality/representativeness assessment through the Pedigree approach. In parallel, a market analysis is carried out for each element under study to identify the main producing countries, main in-use applications and associated commodities, global co-/by-production patterns, and recycling input rate.

Secondly, based on the most relevant LCI datasets selected from the quality and market analysis, LCI models specific to industrial production routes are developed following a harmonised modelling approach (e.g. regarding allocation). Finally, global LCI models, representative of the global market, are derived for each element.

This study reviewed a total of 343 LCI datasets representing industrially established production routes, out of which 185 LCI datasets were selected after analysis (for 54 elements).

For example, for Lithium (Li), nine production routes were modelled that differentiated the main Li commodities, deposits, and producing countries. The carbon footprint from these different routes overall ranges from 5.9 to 52.4 kg CO2-eq/kg Li commodity, with a market average amounting to 19.8 kg CO2-eq/kg Li-2CO3-eq.

The high-resolution LCIs developed in this study eventually contribute to securing the impact assessment not only for metal and mineral commodities supply chains, but also for downstream applications relying on these commodities.

Methodological framework for enhanced and parametric static and prospective mineral LCIs: A case study on copper and nickel in Canada

Marin Pellan[1], Anne de Bortoli[1,2], Guillaume Majeau-Bettez[1]

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The transition toward a net-zero economy requires a substantial increase in the production of various minerals essential for low-carbon technologies. However, incomplete, outdated and low-resolution life-cycle inventory (LCI) data undermine the reliability of Life Cycle Assessment (LCA) results and limit its ability to guide sustainable practices in the metal industry.

This work proposes a methodological framework to develop high-quality parametrized LCIs applied to the case of copper and nickel production in Canada.

The approach builds upon MetalliCan, an open-source database on metal-related production activities in Canada, which offers a high-resolution, site-specific foundation for sustainability impact analysis by integrating detailed data on greenhouse gases, pollutants, water, land, material use and waste generation. These data are leveraged to generate parametrized LCIs for selected metals such as gold, copper, and nickel. To ensure interoperability with existing LCA databases, elementary flows are systematically mapped to ecoinvent-compatible structures.

The modeling framework incorporates data gap-filling strategies using site-specific parameters like deposit type and mining method. It follows a modular structure allowing dynamic assembly of distinct production stages—i.e. mining, beneficiation, and refining—while explicitly representing variability in key parameters such as ore type and ore grade. These parameters are assessed and parametrized using the lca-algebraic tool which allows explicit display of their influence on the environmental performance of metals. The generated LCIs are then projected up to 2050 with the premise tool, providing insights into how evolving technological pathways may influence environmental burdens. Finally, regionalized impact assessment is conducted using IMPACT World+ 2.1 to estimate damage to ecosystem quality and human health.

The results highlight the value of high-quality data and parametric modeling for comparing sustainability performance across production routes and transparently quantifying critical parameters, thus strengthening LCA-based assessments of metals and enhancing their relevance in ESG frameworks and sustainable metal supply chain decision-making.

Towards harmonized carbon footprint and life cycle assessment calculation methods for metals

Markus Berger[1], Sabina Grund[2], Mark Mistry[3], Ladji Tikana[4], Josephine Robertson[5]

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Climate change is one of the major global challenges and there is a proliferation of schemes and standards created to calculate and report carbon footprints (CF). These schemes cover a range of requirements and audiences with differing expectations, which has led to a crowded/complex reporting landscape. To provide internal consistency, the International Council on Mining and Metals (ICMM) undertook a technical review of existing product carbon footprint (PCF) calculation and reporting schemes with the intent of developing a harmonized approach to calculate PCF and LCA results of metals.

First, the current procedure of calculating PCF and LCA results of different metal associations and ICMM member companies were analyzed by reviewing their PCF guidelines (including aluminium, cobalt, copper, nickel, lithium, or zinc) and by conducting bilateral interviews. Additionally, the methodological requirements of relevant standards (ISO 14044 and 14067, GHG Protocol, PEF, etc.) and harmonization activities of relevant industry initiatives (WBCSD Partnership for Carbon Transparency, Catena-X, GBA rulebook, etc.)

have been analysed. In total, 15 guidelines and standards were reviewed and their requirements concerning 18 methodological elements have been compared, comprising e.g. the definition of system boundaries, allocation of metal and non-metal co-products, modelling of electricity, or data requirements. The analysis resulted in a comparison matrix which allowed for identifying areas of consistency but also inconsistency between guidelines.

Taking this inventory as a basis, a consensus finding process was started to develop a harmonized methodological approach on calculating PCF and LCA results of metals. For this a series of online meetings was held between 2023 and 2025 to discuss and agree on the above-mentioned methodological aspects. In addition to achieving internal consistency, alignment to external industry guidelines were considered. This presentation will introduce the methodological recommendations for calculating harmonised PCF and LCA results within the mining and metals industry.

Land-Use-Related Biodiversity Loss Embedded in Global Mining Supply Chains

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Global mining activities have undergone substantial expansion and intensification due to the escalating demand for minerals and metals, spurred by digitalization, infrastructure growth, and renewable energy transition. Such developments push Earth's system closer to the limit of the triple planetary crisis, particularly in biodiversity loss. To mitigate mining-related biodiversity loss, a spatially explicit assessment framework coupled with a comprehensive supply chain analysis is urgently needed. Here, we first derived a land use and land cover map that categorized mining land use separately. Subsequently, mining-related biodiversity loss was quantified by assessing local biodiversity intactness loss and global biodiversity importance at high spatial resolutions. These biodiversity impacts were aggregated at the country level and allocated to specific mining commodities based on the monetary values of the respective extracted metal quantities in each country. Furthermore, the Resolved EXIOBASE3 dataset was used to link mining-related biodiversity loss from production to consumption perspectives. Our findings suggest that global mining leads to a 0.034 % global potentially disappeared fraction. Biodiversity loss hotpots, including Indonesia, New Caledonia, Australia, Brazil, and Peru, account for 57% of the total impact. 82% of mining-related biodiversity impacts stem from extracting coal, precious metals, nickel, iron, and copper. Due to international trade, 77% of mining-related biodiversity footprint is induced in countries other than final consumption. 58% of mining-related biodiversity footprint is driven by demand from China, Europe, Japan, and the USA, particularly in construction, services, machinery, and electronics. This analysis provides a holistic understanding of mining-related biodiversity footprint and identifies levers to mitigate the adverse impacts. Further research is needed to standardize the mapping of mining land use, fill the data gap of mining production, and refine the assessment by increasing the taxonomic diversity and geographic representativeness, providing time series, and quantifying uncertainties arising from species ranges and taxonomic representativeness, among others.

Life cycle assessment of metal recycling and its challenges

Afsoon Mansouri Aski, Christoph Helbig

University of Bayreuth, Germany

Producing metals from mines and making them available for various applications accounts for approximately 14% of global greenhouse gas emissions and 12% of health impacts from particulate matter. Closing global metal cycles and increasing the recycled content provides obvious advantages to resource conservation and avoids waste. In terms of other environmental impacts, applying Life Cycle Assessment (LCA) in the metal industry can help quantify the environmental benefits of secondary production compared to primary production.

Based on an extensive literature review, this study evaluates the environmental impact of the production of the zinc-lead group and their by-products, such as gold, silver, cadmium, and germanium. Recycling provides a significant share of global production for many of these metals. Nevertheless, a core challenge for the industry of this metal group is dealing with energy requirements and reducing the carbon footprint. Regarding LCAs, the International Zinc Association (IZA) compared the environmental impacts of zinc production using only primary resources with a production route containing 14% recycled content. Surprisingly, all impact categories worsened or remained unchanged in the case of higher recycled content, except for Blue Water Consumption.

Despite the IZA study's availability, the literature review findings highlight a notable research gap regarding the LCA of secondary production due to the complexity of metal application across various products and the need for original data from recycling facilities. This research tackles the challenges of zinc recycling LCA studies by improving the LCIs of the recycling process using HSC chemistry simulation software due to the transparency and reproducibility of data. The results assist in finding the optimum recycling conditions and enhancing the LCA interpretation by making use of various scenario modelling, such as different waste compositions or process efficiencies.

Control Variables for definition of Absolute Sustainability Boundaries for Mineral Resources

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In Absolute Environmental Sustainability Assessments (AESA), environmental impacts from a product system are compared to its assigned share of a carrying capacity (also referred to as absolute sustainability boundary). For climate and ecosystems, boundaries are well established, while for mineral resources, the definition of sustainability boundaries is not straightforward and lags behind. In our earlier work we have scrutinized the lines of thinking that have led industrial ecologists and other scientists to propose absolute boundaries for mineral resources. We found that the currently proposed boundaries for use of mineral resources lack the maturity required for reliable use as absolute boundaries in AESA. This includes methodological inconsistencies and a general lack of consensus on Areas of Protection or the choice of control variables and their location in the impact pathway. To advance the absolute sustainability assessment of mineral resource use we (1) identify mechanisms that have the potential to lead to the transgression of an absolute boundary for mineral resources due to their impact on the recently defined accessibility-based area of protection for resource use. In parallel, we (2) identify processes in the impact pathway that are irrelevant for transgressing a potential mineral resource boundary because they focus on control variables that are irrelevant for an accessibility-based area of protection for resource use. Finally, we (3) suggest which control variables are suitable candidates for the definition of an improved boundary for mineral resources.

Sustainability in Critical Raw Materials for Energy Transition: Identification of Sustainability Indicators and Categories Through a Multivocal Literature Review

Francisco Encina, Christian Thies

Hamburg University of Technology, Germany

The global energy transition has increased the demand for critical raw materials (CRMs) such as lithium, cobalt, and copper, which are essential for energy storage and conversion technologies like electric vehicle batteries. While these materials play a vital role in reducing greenhouse gas emissions, their extraction and supply chains cause significant environmental and social impacts. Existing research often focuses on isolated aspects, regions, or stages of CRM supply chains, and frequently neglects industry perspectives, limiting its practical applicability.

In the "Manufacturing-as-a-service and supply chain predictive twin for critical raw materials" (MaaSiveTwin) project, co-funded by the European Union and the Swiss Confederation, we collaborate with both industry partners and academic institutions to bridge this gap. We focus on grey literature, such as industry reports, which offer recent insights and strategies that address the challenges faced by practitioners, making it a vital complement to academic research. By employing a multivocal literature review (MLR) that integrates these diverse sources, our research balances academic rigor with practical relevance, ensuring actionable outcomes for both scholarly and industry stakeholders.

This study identifies critical sustainability indicators, risk hotspots, and assessment frameworks for CRM management. It also uncovers discrepancies between academic and industry perspectives, highlighting underexplored areas in existing literature. The findings provide actionable insights for improving life cycle-oriented assessment methods and advancing equitable, sustainable CRM supply chain management. By addressing the trade-offs between environmental and social impacts and benefits of CRMs, this research contributes to a more sustainable approach to the global energy transition.

Moving on from existing models for life cycle inventories of tailings impoundments: case studies of a better method

Mike O'Kane[1], Johannes Drielsma[2]

[1]Okane Consultants, Canada; [2]Drielsma Resources Europe, Netherlands

During a workshop at the SETAC Europe 34th Annual Meeting in 2024, a group of metals ecotoxicologists and experienced LCA practitioners proposed that existing models projecting to 60.000 years are not reliable in a regulatory context, and new models limited to a 500 year timeframe could yield more realistic life cycle inventories (LCIs) for tailings impoundments. This work was followed up at SETAC Europe's 26th LCA Symposium, where Raymond et al., (2024) proposed a simplified, yet sensitive conceptual model of the factors most influencing releases from tailings over that timeframe, including the regional setting, missing unit-processes of the product system, and resulting geochemical phenomena. This presentation will follow-up with results from ground-truthing of the model at a small number of archetypical sites. The results will demonstrate that, for LCA studies, accurate categorisation of regional settings and utilised technologies over 500yrs have a higher correcting power for estimating releases from mine tailings impoundments than precise geochemical modelling over 60.000 years.

Key Environmental Hotspots and Sensitivity Analysis in Pilot-Scale Metal Recovery from Acid Wastewater

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In recent decades, it has been highlighted that the European Union is highly dependent on third-party countries for imports of critical raw materials, which are essential for various industrial applications. This dependency, further emphasized by the Critical Raw Materials Act, is driving initiatives toward a more efficient and sustainable exploitation of resources located within Europe (e.g. Horizon Europe project ReSilex. Grant number 101058583). These raw materials are found not only in active mining operations but also in the waste generated during these operations. Such wastes can be an opportunity to be used as secondary sources for the recovery of valuable metals, reducing the reliance on imports. Therefore, a novel process has been developed to recover metals from acid mining wastewater. Based on experiments carried out at laboratory scale along with information obtained from literature, a pilot plant has been designed and implemented to scale up the process, allowing for optimization of the various recovery stages involved. While the recovery of metals from secondary sources is essential to preserve mineral capital, avoid dependency on external suppliers, and mitigate the depletion of primary mining reserves, the sustainability of such processes is also important. For this reason, environmental impacts will be evaluated using the life cycle assessment (LCA) methodology for the pilot plant developed. Accordingly, Sustainability will be assessed by identifying the main hotspots with the highest impacts within the process and conducting a sensitivity analysis to explore potential reductions in these impacts.

Session 1.06: Sustainable Underground Construction In Pipeline Infrastructures

Time: Wednesday, 10/Sept/2025: 9:35am - 11:05am
Session Chair: Stefan Schmitz, TRACTO-TECHNIK GmbH & Co. KG, Germany
Session Chair: Andreas Redmann, Kunststoffrohrverband e.V., Germany

Trenchless Technologies for modern and sustainable infrastructures

Alexandra Kalnev[1], Stefan Schmitz[1], Monu George Varghese[2], Zaid Hashash[2]

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In an era where sustainability and efficiency in construction are becoming increasingly important, trenchless construction methods offer innovative solutions for the development and maintenance of modern infrastructures. This paper provides an overview of the various trenchless methods and their applications, from house connections and distribution networks to the rehabilitation of existing pipelines.

Trenchless construction methods enable the installation or renewal of underground infrastructures without excavating the surface. This reduces environmental impacts and disruptions to the public. In addition it also contributes to cost efficiency and shorter construction times.

Special attention is given to the significance of these technologies in the context of global challenges. These include reducing water losses due to leaking pipes, expanding infrastructure in growing urban areas, and adapting to climate change. By applying trenchless methods, cities and municipalities can modernize their infrastructure while simultaneously achieving their sustainability goals.

The European Green Deal, which aims to make the EU climate-neutral by 2050, plays a central role in this context. Promoting sustainable construction methods is a key part of this strategy to reduce greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels. Trenchless construction methods support these goals by providing resource-efficient and environmentally friendly solutions.

Through case studies and practical examples, this paper illustrates how trenchless construction methods can contribute to the creation of sustainable and resilient infrastructures. These examples demonstrate the successful implementation in various projects worldwide and highlight the versatility and effectiveness of these technologies.

Hard-coupling MFA and LCA to assess the sustainability of plastics circularity in Germany's building and infrastructure sector

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Global plastic demand has been growing exponentially and is expected to also rise in the future. The circular economy paradigm imposes that an increasing share of this demand for all types of polymers be met through recycling. In sectors using long-lived plastic products however, the presence of so-called "legacy contaminants", i.e. additives that underwent some level of restriction since the product's manufacturing, is jeopardizing circularity potentials, as their reintroduction would not comply with current legislation. This is exemplified by the German building and infrastructure (B&I) sector, within which recycling is potentially limited by the presence of contaminants in its plastic stock.

In this work, we couple a high-resolution dynamic material flow analysis (MFA) model with a prospective

life cycle assessment (LCA) model. A generic life cycle inventory (LCI) is developed and used as a structure to model the end-of-life (EOL) treatment activities of various polymers, accounting for their respective legacy contaminants. Here, the dynamic MFA model, developed using the ODYM package, serves as a data source for flows, transfer coefficients, and concentrations, which feed the generic LCI, using specific mapping and brightway as the LCA software package. This process produces tailored LCIs for the EOL treatment of polyurethane, polystyrene, polyethylene, or polyvinyl chloride for the modelling period from 2023 to 2100, which can be readily used for the life cycle impact assessment of various scenario combinations (e.g., growth vs. saturation of plastics demand, SSPs, shorter or longer lifetimes, …). Combined results indicate that life cycle environmental impacts may rise with stricter regulations on the reintroduction of legacy contaminants. Overall, the study shows that such an automated and flexible framework can prove highly useful to provide policy-relevant results over the various dimensions of sustainable plastic value chains.

Life Cycle Assessment (LCA) in the Decommissioning of the Oil & Gas Industry: Impacts on Reverse Logistics and Recycling of Flexible Pipelines in Brazil

Lucas Caldas[1], Isabela Oliveira[1], Ana Carolina Angelo[2], Marcelo Igor Souza[1]

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The decommissioning of offshore structures is a complex and costly process, with subsea equipment requiring particular attention due to its sensitive nature and the logistical challenges associated with its decommissioning. In Brazil, decommissioning is governed by a specific resolution that mandates the complete removal of structures, except in exceptional cases where assessments justify partial or total in situ retention. As a result, decommissioning presents the opportunity to generate material waste that can be recycled within the framework of the Circular Economy (CE), providing environmental benefits to various industrial sectors. This study aims to assess and quantify the potential environmental and logistical impacts of recycling flexible pipelines, with a focus on the separation and final disposal of scrap steel, polymers, and stainless steel, using primary data from a Brazilian recycling company. The Life Cycle Assessment (LCA) methodology was applied, considering the current processing stage and exploring various improvement scenarios, such as the adoption of renewable energy through photovoltaic panels and reducing transport distances by lorry. The Ecoinvent v.3.8 database was used to support the analysis. The results show that the most significant inputs in the pipeline dismantling process are diesel and electricity. Furthermore, the reverse logistics was identified as the main hotspots, i.e. the transport of the pipelines from the port of origin to the final disposal of the co-products generated during the process. The study concludes that the most effective strategy for reducing environmental impacts is to minimise transport distances, e.g. limiting it to 500 km can reduce impacts by over 50%. This research makes a valuable scientific contribution by addressing a topic that has been little explored in the literature. It also highlights the importance of onshore stages, logistics, and the selection of companies within the recycling chain, promoting a more CE in the Oil & Gas sector.

Tackling PVC Challenges: Multi-Criteria Evaluation of Sustainable PCR-PE Electrical Pipes

Bruna Machado[1], Gustavo Kampa[1], Natália Ladeira[1], Luís Silva[2], Catarina Dias[2], Bruno Silva[1], Catarina Basto-Silva[1]

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Polyvinyl chloride (PVC) is the third most widely used plastic and is valued for its strength, durability, and lightweight properties. However, PVC's extensive use in construction, piping, and consumer goods raises significant environmental and health concerns throughout its lifecycle.

The RECY.TUBE project addresses these challenges by developing sustainable alternatives for electrical pipes, replacing PVC with Post-Consumer Recycled Polyethylene (PCR-PE). Additionally, non-halogenated flame retardants derived from organic and inorganic materials are incorporated into the formulations.

This study evaluates six innovative composite formulations using a decision-making matrix based on four key criteria: flame retardance, processability, cost, and environmental performance. Flame retardance, considered as an obligatory criterion, was assessed using the UL94 flammability standard. Environmental impacts were analysed in accordance with ISO 14040:44 standards, utilizing the Ecoinvent database, SimaPro software, and the EN 15804 impact assessment method. A cradle-to-gate approach was adopted, with the declared unit defined as "the production of 1 kg of electrical pipe." Costs were evaluated based on raw material prices.

Of the six formulations studied, two received null scores for failing to meet the flame retardance criterion. Among the remaining four, a leading formulation, comprising 75% PCR-PE and 25% flame retardants, demonstrated a balanced performance across technical, economic, and environmental considerations. The other three formulations achieved lower overall scores; one notable example, despite exhibiting excellent flame retardance, performed poorly in both economic and environmental assessments, making it the least favourable option.

This study demonstrates the value of integrating technical performance, process efficiency, cost-effectiveness, and environmental impacts into a structured decision-making framework. The findings underscore the potential for sustainable materials to replace PVC, advancing safer and more responsible solutions for electrical pipe applications.

This research was supported by the NextGenerationEU program as Recovery and Resilience Facility Plan applied in Portugal, with the code number RE-CO5-i01.02 Sustainable Plastics, WP3 PPS10 RECY.TUBE.

Plastic pipes for a sustainable infrastructure

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Kunststoffrohrverband e.V. (KRV), Germany

For decades, plastic pipes have been used in different infrastructure applications. Several aspects demonstrate sustainability: Workability, modularity, repairability, recyclability.

Right from the start of product development and product design, the aspects of workability on the construction site, modularity of the products and repairability are given priority. Plastic pipes, therefore, meet all the requirements of the demanding EU regulations in the Ecodesign Directive as well as the Ecodesign Regulation and central goals of the National Circular Economy Strategy.

Plastic pipes are mechanically recyclable to a high degree, up to 100% depending on the material. The state of the art requires the use of virgin materials for a few safety-relevant applications such as drinking water or gas pipes. The increasing processing of recyclates in other areas of application (including from other plastic products) is an important contribution to the conservation of resources and, therefore, also to

sustainability.

Plastic pipes are characterized by a service life of over 100 years and offer the advantages of good workability, modularity, repairability and recyclability in relation to the topic of “ecodesign”. Plastic pipes are highly resistant to aggressive media, such as wastewater and chemicals, and are resistant to contact with hydrogen and CO2. At the same time, they have a high level of flexibility and, therefore, a high level of safety under load.

Due to their low weight and material properties, they can be transported cost-effectively and easily handled on site, for example, as a coil or on a drum.

Wastewater Pipe Restoration: Which is Ecologically Superior – Replacement in Open Cut or Cured-in-Place?

Jan Blömer, Daniel Maga

Fraunhofer UMSICHT, Germany

The wastewater system in Germany requires the renewal of 100 000s of kilometers in the next years. This study compares the ecological impacts of two possible options: Replacement of the old pipes by new concrete pipes in the open cut technology (OC) and a cure in place pipe (CIPP) technology, where an uncured glass fiber inliner is placed in the old pipe and cured in place.

The inliner are based on glass fibers and polyester resin, i.e. they are based on fossil, carbon-containing raw material. The concrete pipes release carbon dioxide particularly during cement production but do not contain carbon. The climate impact potential at the end-of-life varies accordingly.

The evaluation of both technologies is based on primary data of German manufacturers. The LCA results show already advantages in various impact categories (including GW) for the inliners during the production stage. The main ecological advantage of the inliners is the drastic reduction of the installation effort and the omission of the need to rebuild surface structures (e.g. asphalt pavement). However, this is very case specific.

It is assumed that the service life of both technologies is identical (100 years) and that the maintenance effort is identical, too, which is why the use stage is excluded. The long service life makes the modelling of EoL challenging, especially for the inliners. Concrete material can be crushed and reused as building material while the optimal, future technology for inliner material is not clear, yet. Today, the use of the inliner material in cement kilns seems to be a very effective way because the polyester is used as fuel and the glass is incorporated in the cement leaving no waste.

The contribution shows a comparison on all PEF impact categories, including normalization and weighting. Furthermore, the sensitivity to various technological assumptions is shown.

Session 1.07: LCA in Policy: Frameworks, Compliance & Placement Part I

Time: Wednesday, 10/Sept/2025: 11:30am - 1:00pm
Session Chair: Antonio Valente, ecoinvent, Switzerland
Session Chair: Diego Iribarren, IMDEA Energy, Spain

Paving the way for the first product environmental footprint category rules for hydrogen systems: product categorisation and next steps

Khaoula Ben Hnich[1], Sumanth .K.R Maddula[1,2], Claudio Carbone[3], Alessandro Agostini[3], Tarik Nawaya[4], Olga Bereketidou[5], Raphaël Brière[6], Simone Maranghi[7], Alessandra Zamagni[7], Till M. Bachmann[8], Davide Beretta[8], Giorgia Galvini[9], Diego Iribarren[1]

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Setting product environmental footprint category rules (PEFCRs) specific to hydrogen devices arises as an urgent need to support the establishment of a sustainable hydrogen economy motivated by the energy transition. The HyPEF project aims to develop and apply these rules by following a methodological framework aligned with the Commission Recommendation (EU) 2021/2279. Within this context, the present work presents the latest developments in (i) setting product categories and subcategories through the hydrogen value chain, and (ii) subsequently defining and assessing representative products.

Product categorisation is a challenging step due to intricate connections between the devices involved in the hydrogen life cycle. For the sake of simplification, the hydrogen value chain was divided into five families: production, conditioning, storage, transport, and use. Then, the identification and definition of product categories and subcategories was carried out according to horizontal and vertical rules focusing on common functions and differences in terms of, e.g., potential representative product, potential environmental hotspots, and benchmark. As a result, 11 product categories and 14 subcategories of hydrogen-related devices were defined with an appropriate granularity that avoids undesired proliferation of PEFCRs due to narrow scopes while ensuring relevance to function and users in favour of an efficient and effective development of PEFCRs.

Hydrogen-specific product categorisation was followed by the identification of potential representative products for selected (sub)categories such as 'electrochemical devices for hydrogen production', 'tanks for compressed hydrogen storage for heavy-duty mobility', and 'hydrogen fuel cells intended for electricity production'. Overall, the proposed product categorisation and the identification of the representative product's hotspots pave the way for the first PEFCRs for hydrogen systems. This work has been carried out in the context of the HyPEF project, which is supported by the Clean Hydrogen Partnership and its members. HyPEF is funded by the European Union (Grant Agreement No 101137575).

The role of LCA in policy for enabling Sustainable Consumption and Production : A case study of South Africa

Valentina Russo, Kolobe Chaba, Taahira Goga, William Stafford, Anton Nahman

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The relationship between LCA and policies aimed at promoting sustainable consumption and production (SCP) is a two-way street. On one hand, LCA can inform policies targeting high-impact products/activities, by identifying key policy issues, comparing solutions (ex-ante) and evaluating implementation (ex-post). On the other hand, policies can promote the use of LCA and improvements across the product lifecycle, through voluntary or mandatory assessment, incentives, limits or thresholds for compliance.

South Africa (SA) recently became one of the first countries to include LCA as a mandatory requirement within the Extended Producer Responsibility (EPR) Regulations (DFFE, 2020). The Regulations require producers of identified products in six sectors to conduct LCA studies in relation to their products; aimed at minimizing material use; redesigning products to facilitate reuse, recycling or recovery; and reduction of environmental toxicity of the post-consumer waste stream (DFFE, 2020). In a country with a shortage of LCA capacity and only a limited number of LCAs conducted to date; this policy requirement will become a strong driver for increased application and uptake of LCA.

At the same time, LCAs have recently had an impact on policy in SA. For example, a Life Cycle Sustainability Assessment study on grocery carrier bags informed amendments to the country's plastic carrier bag regulations (DFFE, 2021). Specifically, based on the results of the LCSA, the amendments specify targets for an increased percentage of recycled content in plastic carrier bags.

More recently, an LCA study of green ammonia aims to help inform project design (ex-ante) and the development of harmonised standards for the certification of green hydrogen and its derivatives as low-carbon e-fuels. In addition, this research and its findings are informing the development of a green hydrogen certification standard for SA.

This paper presents case studies of the relationship between LCA and policies for SCP in SA.

Recalibrating the Circular Economy Transition in carbon intensive industry sectors: Informing EU policies with life-cycle based assessment

Anna M. Walker, Paola F. Albizzati, Leonidas Milios, Pablo Piñero Mira, Davide Tonini

Joint Research Centre of the European Commission (JRC), Spain

On the path of the European Union towards net-zero emissions, the carbon-intensive industries are in the focus of policy makers. While decarbonisation efforts including the electrification of the energy grid are indispensable, more circular material use has frequently been proposed as an important part of the solution. With a lifecycle perspective, the circular economy (CE) concept allows for analysing material flows from raw material extraction through production, use phase and end of life, with the goal of closing material loops. However, environmental and socio-economic impacts at sector level have yet to be measured, as to create quantitative underpinning of policy instruments supporting CE interventions. Our lifecycle-based analysis of the most carbon-intensive EU industry sectors – steel, cement, plastics and aluminium – aims to create a better understanding of potential points of policy interventions. A multi-method analysis of potential CE strategies to be implemented in the EU by 2050 is conducted, consisting of three parts. The first is a material flow analysis, combined with life cycle assessment and life cycle costing to determine bottom-up environmental and economic impacts. The second is an environmentally extended input output analysis, to characterise the spill-over effects of CE interventions into other industries, covering both environmental and socio-economic aspects. Finally, these two methods are complemented by a dynamic macro-economic analysis using FIDELIO, a demand driven model to capture potential economy-wide pricing and rebound effects. The synthesised result of these three methodologies show that CE interventions

related to the reduction of material use are overall most environmentally beneficial, but induce trade-offs for the socioeconomic dimension. These findings allow for the creation of a robust policy mix with interventions along the whole value chain of the carbon-intensive materials. Hence, policy supporting CE interventions has the potential to serve both the principles of decreasing resource dependency and sustainable competitiveness.

The EU environmental policy landscape in a nutschell

An De Schryver, Luca Zampori

PRé sustainability, The Netherlands

The environmental policy landscape in the European Union is changing fast. With the circular economy action plan, adopted first in 2015, and later reinforced through the EU Green Deal, drafted end 2019, sustainability as a whole moved suddenly to the top of most political agendas. It came with a large number of initiatives that include life cycle thinking and which have been further worked upon by policy makers since. Today, most legislative proposals have been drafted, covering sustainability aspects for not only products, but also organisations. They range from mandatory reporting to voluntary focus on sustainability during the product design phase, while some of them explicitly refer to the use of LCA or PEF, others talk about a life cycle thinking or GHG accounting. It is important to stay informed as several regulations are just around the corner and time for preparation is essential. Examples are (i) the Ecodesign for sustainable products regulation who introduces a digital product passport for products made available on the European market and (ii) the Corporate Sustainability Reporting Directive that requires GHG reporting for companies with a turnover above €150 million. This presentation will provide an overview of the most important EU regulations in the field of sustainability. It will give insights in which regulations require or suggests the use of LCA or PEF, where they are in the policy development cycle (draft proposal, adopted or entered into force) and what the technical requirements are so far.

Integrating Risk, Performance, and Sustainability: Life-Cycle Assessment as a Cornerstone for Safe and Sustainable by Design Lubricants

Jonas Hoffmann, Andreas Ciroth

GreenDelta, Germany

Emerging products in the transition to a low-carbon economy require robust sustainability assessments to ensure environmental, economic, and social compatibility. Among these, lubricants are pivotal for energy-related sectors, where effective friction and wear management significantly influence energy efficiency and emissions. However, conventional lubricants pose notable environmental and health risks, driving the need for novel, sustainable alternatives.

The Horizon project SiToLub addresses these challenges by developing Safe and Sustainable by Design (SSbD) lubricants in compliance with the Joint Research Centre (JRC) framework. Life-cycle assessment (LCA) plays a critical role in evaluating SSbD compliance, serving as the overarching methodology to integrate toxicological and performance criteria. The SiToLub's own SSbD approach incorporates risk and biodegradability evaluations derived from Quantitative Structure-Activity Relationship (QSAR) methods, alongside performance attributes such as wear protection and thermo-oxidative stability, simulated through reactive molecular dynamics (rMD). Hence, LCA will be the overarching framework for integrating performance but also risk leading to a integrated Risk and Performance Life-Cycle Assessment (iRP-LCA).

To meet SSbD principles, we benchmarked a novel soybean-based lubricant against a conventional petroleum-based counterpart. A cradle-to-gate assessment revealed higher eutrophication and toxicity impacts for the bio-based lubricant, primarily due to agricultural inputs. Surprisingly, climate change and fossil

resource use impacts were also higher, resulting in the conclusion that novel technologies are intrinsically disadvantaged compared to well-established products. To address this, we conducted comprehensive life-cycle assessments of novel lubricants and components, encompassing the entire life cycle—including use and end-of-life (EoL) phases—and integrating performance, toxicity, and biodegradability parameters. This analysis reveals reduced environmental impacts for bio-based lubricants and highlights a holistic assessment already at early development stage.

We here highlight the value of iRP-LCA in the SSbD assessment by bringing criteria like risk, performance, and sustainability into one overarching methodology.This will ease the development of emerging functional products.

Anticipating Carbon Footprint Regulations for Aggregates: A New CO2-Calculator for Compliance and Strategic Insights

Léa Fischer, Koji Negishi, Renaud De Montaignac

ORIS Materials Intelligence, France

Aggregates are indispensable to the construction industry, with applications ranging from road bases and railway ballast to concrete and asphalt. Despite global consumption reaching billions of tonnes annually, their relatively low carbon footprint (4–11 kg CO2eq/t) has historically drawn less attention compared to other building materials. However, the new European Construction Product Regulation (CPR), effective from December 2024, introduces mandatory carbon footprint declarations for all construction products by December 2025.

For aggregate producers, this highlights the complexity of determining carbon footprints at a product-specific level, as current methods often lack the flexibility needed for such calculations. To address this gap, ORIS has developed an advanced CO2-calculator providing practical and adaptable solutions.

The tool operates by dividing production sites into production areas, which are defined by their specific inputs, outputs, and energy consumption. These areas are linked through flowsheets that trace material and energy flows. Energy consumption is allocated proportionally to materials based on mass flows, resulting in a carbon footprint for outputs from each area. Users can either adopt a site-wide average footprint for their aggregates or define commercial products with specific compositions (e.g., "0/8 aggregate" as 80% from Area 2 and 20% from Area 3).

Preliminary analyses of over 100 products reveal footprints ranging from 0.3 to 48.9 kg CO2eq/t, influenced by site type, aggregate size, electricity mix, drying processes, and the use of explosives. Insights show the energy intensity of drying and the significant impact of natural gas-powered systems.

This tool not only ensures compliance with the CPR but also empowers decision-makers to optimise processes and craft sustainability strategies. Observed GWP variations underscore the need for detailed analyses tailored to aggregates, supporting transparency and accurate environmental impact reporting.

Footprint Semantics: Communicating LCA Results, Avoiding False Precision

Gregory A. Norris[1], Joel Mertens[2], Jeremy Lardeau[2], Ajay Gupta[1]

[1]MIT, United States of America; [2]Cascale

A challenge in LCA communication is avoiding false precision. Statistics are not accessible to non-specialists. Additional communication challenges arise because impact units are not familiar, magnitudes can be unfamiliar, and audiences lack intuition about whether impacts are small or large in absolute terms.

We present a four-step approach for use in communicating LCA results designed to address these challenges. Step 1 is normalization: dividing by global average per capita impacts, whenever results will be com-

municated to third parties.

Step 2 addresses the problem of interpreting and comprehending results which may arise across many ranges of magnitude. Normalized results lower than 1 are expressed in the amount of time which corresponds to the appropriate fraction of a year. For example, 1 day is 1/365th of a year of per capita impacts. Normalized results up to 100 can be expressed as years, results to 10,000 can be expressed in centuries. For larger results we use the convention that 10,000 persons is a “town”, 1 million persons is a “city” and so-on.

Step 3 employs round numbers. We propose the use of numbers 1, 2, 5, 10, 20, 50, and 100 to express any value between 1 and 100. Numbers greater than 100 in one time unit (minutes) can be converted to a number less than 100 in another time unit (hours).

Step 4 is to express more uncertain results using ranges bracketed by round numbers, such as 2-10 hours, or 5-50 centuries. We give examples and invite discussion.

A white paper on the comparability of Environmental Product Declarations (EPDs) for diverse stakeholders.

Katrin Müller[2], Elina Iakimova[1], Johannes Auer[2]

[1]Siemens SA, Portugal; [2]Siemens AG, Germany

Environmental Product Declarations (EPDs) have become a crucial means of communicating the environmental impacts of products across a range of industrial sectors. However, despite their growing adoption, significant challenges remain in ensuring the comparability of EPDs, primarily due to differences in methodologies, datasets, and standards.

This white paper addresses the critical issue of comparability of EPDs, providing a foundational resource for diverse stakeholders. It aims to enrich sales and procurement activities, raise awareness on how to interpret EPDs and foster customer acceptance, and contribute towards policies harmonization. The paper outlines the basics of Life Cycle Assessment (LCA) and EPDs, detailing the relevant standards, methodologies, and key elements that influence EPD results. It also offers a comprehensive overview of Siemens’ EPD Type II creation process and explains its high quality, accuracy and reliability.

In addition to these objectives, this paper lays the groundwork for industry-wide alignment by addressing how EPD comparability can be improved. This position can facilitate aligned communication and collaboration with key industrial players, driving collective efforts towards harmonizing EPD practices. In essence, this white paper can serve as a starting point of an international collaborative endeavor, with the objective of establishing a consistent EPD ecosystem that represents a fundamental component of global sustainability initiatives.

Implementing Eco-Efficiency in State Enterprises: A Step Toward Sustainability

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In 2020, the State Enterprise Policy Office (SEPO), Ministry of Finance, initiated the concept of promoting sustainable development by incorporating Eco Efficiency (technical supported by National Science and Technology Development Agency -NSTDA) as one of the organizational indicators. This approach focuses on enhancing value, reducing resource usage, and minimizing pollutants generated by the activities of the organizations. This concept has played an important role in transforming the operations of Thai state enterprises and has marked the beginning of significant changes across multiple areas, leading to continuous development for more than 5 years. Currently, over 40 state enterprises, which are fully or partially owned by the government and operate in sectors such as transportation, energy, industry, financial institution, and utilities, are required to report on Eco efficiency.

The implementation process of Eco-efficiency uses the concept of the life cycle approach, which considers the entire life cycle of a product or an organization and weighs environmental impacts alongside economic performance. However, there are no restrictions in mandating the selection of both parameters at the beginning of the process. It is generally based on the context of each business and has similar key objectives, such as transparency in reporting data, developing strategies for organizational sustainability, resource conservation, and improving policy management of Thai state enterprises. However, challenges such as data availability, complexity, and subjectivity are issues that each state-owned enterprise should find solutions.

The results of the implementation show that many organizations are committed to making changes in various areas, such as setting clear eco-efficiency metrics in the long term, promoting circular economy practices, supporting energy and resource efficiency, driving economic growth with reduced environmental impact, as well as promoting innovation and technological development. Several enterprises are also aligning with global sustainable development goals (SDGs).

Session 1.08: PCF data: Achievements and challenges for sector-specific guidelines in industry

Time: Wednesday, 10/Sept/2025: 11:30am - 1:00pm
Session Chair: Martina Prox, iPoint-Systems gmbh, Germany
Session Chair: Peter Rudolf Hans Saling, BASF SE, Germany

Application of the new PCF Guideline of Together for Sustainability (TfS) in various examples

Peter Rudolf Hans Saling, Nicola Paczkowski, Alessandro Pistillo, Anahi Grosse-Sommer, Richard van Gelder, Jenny Reuber

BASF SE, Germany

The recently published PCF (Product Carbon Footprint) Guideline by Together for Sustainability (TfS) marks a significant advancement in the chemical industry's efforts to enhance sustainability across various sectors. This guideline provides a comprehensive framework for calculating and reporting the carbon footprint of chemicals, enabling companies to better understand and manage their GHG emissions impact.

By providing a sector-specific approach to carbon footprint calculation, the guideline ensures consistency and comparability across different companies and sectors. It supports the application of the guideline as drop-in solution in other industries using chemicals for different purposes. This facilitates more accurate PCF calculations, enables comparisons of results and helps to identify improvements by companies. In addition, it provides a harmonized approach developed by the 54 member companies of TfS for the performance assessment of chemicals.

The guideline promotes transparency in reporting, allowing stakeholders to gain a clearer understanding of the environmental impact of chemical products. This transparency is crucial for building trust and credibility with customers, regulators, and investors. With detailed insights into the carbon footprint of their products, companies can make more informed decisions regarding process improvements, resource allocation, and sustainability initiatives. This leads to more efficient operations and reduced GHG emissions. Adopting the PCF Guideline can provide a competitive edge by demonstrating a company's commitment to sustainability. This can enhance brand reputation, attract environmentally conscious customers, and open up new market opportunities.

The new PCF guideline covers many new methodological elements and describes for example more in details the PCF assessments for CCU, Mass balance, multioutput processes and the assessment of waste streams. Additionally, data quality ratings were harmonized with other frameworks.

The presentation will show the application of the guideline to specific calculations and examples. It will address achievements and challenges and exchange them with other practitioners.

Toward an increasing standardization of LCA data reporting: the experience of aluminium's industry

Benedetta Nucci[1], Sanaa Zinbi[1], Francesca Reale[2], Alessandra Zamagni[2], Gioia Garavini[2]

[1]European Aluminium, Belgium; [2]Ecoinnovazione, Italy

With the increasing demand for high-quality primary LCI and LCA data from downstream industries and regulatory bodies, the need for consistent calculation approaches has become evident. While the concept of standardized methodologies and sector-specific guidance for calculating environmental footprints is intuitive as a contribution to the achievement of consistency, practical implementation poses significant challenges, particularly for raw materials like aluminium, which are used across multiple markets.

Moreover, as downstream markets increase their demands, independent initiatives may lack sufficient uniformity, necessitating benchmarking against established frameworks. The ongoing efforts of Catena-X and PACT to benchmark sector-specific guidance against fixed principles aim to enhance standardization, ensuring the consistency and comparability of calculations. For the building industry, by contrast, the European standard EN15804 and Environmental Product Declarations serve as the primary references for achieving greater harmonisation.

Meanwhile, European legislation is becoming increasingly prescriptive about calculating and reporting carbon or environmental footprints. In addition, among the life cycle-based calculation methods, the Product Environmental Footprint (PEF) stands out as a recommendation or requirement in several policy documents, requiring the development of product category rules to ensure effective implementation.

Given that aluminium is one of the most widely used metals across various markets, these developments significantly impact the industry's efforts to standardize the reporting of LCI and LCA data along the value chain. This paper shares the aluminium industry's experience with these standardization efforts, highlighting the primary challenges, lessons learned, and future hurdles in achieving uniform LCA data reporting. The focus is on meeting both market demands and legislative requirements. Key aspects discussed include the development of sector-specific guidance and a common LCA model aligned with ISO standards, benchmarking against Catena-X and PACT, creating category rules aligned with EN15804, and ultimately developing an aluminium-specific PEFCR.

Implementation of an IT solution for Portfolio-wide PCF calculation at a Multi-national Chemical company

Ananda Sekar[2], Zohra Salhi[1], Shaikh Rasool[2], Muhammed Zeeshan Anwar[2], Suvayan Guha Ray[2], Drishya Chandran[2], Abdulaziz Ahmed[2], Amit Khandelwal[1], Maike Horlacher[1], Yannick Bernard[1], Martijn Gipmans[1]

[1]Sphera Solutions GmbH, Germany; [2]SABIC, Saudi Arabia

The chemical industry as an enabling industry offering products and solutions for many downstream industries and as such is a key actor for achieving decarbonization in value chains. This presentation explores the complexities and methodologies involved in calculating the Product Carbon Footprint (PCF) across the complete portfolio in a large multi-national petrochemical company for thousands of products. It examines the challenges and nuances of applying multiple standards and certifications, including TfS, CBAM, ISCC, and mass-balance principles, in the calculation and management of PCF for a multi-feedstock product system. Central to the discussion is the need for a tailored PCF Methodology document, which addresses the compliance with various Standards and Sectoral Guidelines, management system, accounting of various responsibilities in the entire data flow, change management processes and the handling of inventory data sources and quality.

The presentation highlights the intricacies involved in balancing secondary data and primary supplier-specific data, allocation of renewable energy across assets and the impact of residual grid mixes. Attention is also given to the structuring of data, the definition of system boundaries, handling of process recycle

streams, standardization needs in raw data and the treatment of emerging considerations such as Carbon Capture and Utilization (CCU) and biogenic CO2.

Further, the presentation addresses the complexities of handling data from both digital and non-digital platforms within an organization, emphasizing the importance of data conditioning for consistency. Lastly, it covers key considerations for developing automation tools that can accommodate the complexities of diverse certifications and standards and ensuring accurate and consistent PCF modeling across varying systems and regulatory landscapes.

Supporting reproducible and standardized product carbon footprints by stricter guidelines and certification under ISCC CFC

Jana Gerta Backes[1], **Patrick Ober**[2], **Stefan Gärtner**[1], **Stefan Majer**[3]

[1]Meo Carbon Solutions GmbH; [2]ISCC System GmbH; [3]DBFZ GmbH

This contribution aims to standardize and improve comparison of the Life Cycle Assessment (LCA) and the Carbon Footprint (ISO 14067) using a carbon footprint certificate (ISCC Carbon Footprint Certification (CFC)) and second, use a case study as example to bring the distribution of emissions into line by making use of a mass balance-based approach which is widely adopted in industries co-processing conventional with fossil feedstock.

The European economy is increasingly dependent on scientifically sound and robust methods for carbon footprinting on company as well as on product level. This is important to support reporting duties about the requirements from the EU Commission (e.g., in non-financial reporting) or in relation to the Carbon Border Adjustment Mechanism (CBAM). Furthermore, different industries are following internal target pathways for the reduction of Greenhouse Gas (GHG) emissions – all still using a diversity of schemes and approaches.

ISCC is currently developing a sector-independent Carbon Footprint Certification (CFC) approach, which further specifies the rules and guidance in existing standards. This, by e.g. increasing and sharpening the requirements for inventory and impact assessment. Furthermore, the methodology will provide a certain flexibility to system users, e.g., by using mass balance-based allocation approaches, allowing to distribute or allocate emissions to product batches, while ensuring that the accounting and allocation of the overall emission inventory remains sound and reproducible. In particular, the emission distribution approach based on the mass balance is demonstrated with the help of a primary-data case study. We place our focus on the CO2-heavy parts of common supply chains, examining our approach from both, an industrial and a scientific perspective – including the specific development for a sector-independent ISCC CFC.

The chosen approach and certificate are of particular interest in the cradle-to-gate system boundaries in the manufacturing industry but also raise other relevant future questions for the circular economy and end-of-life modelling.

Evaluating the applicability of the current dissipation-based life cycle impact assessment methods for addressing carbon resource

Thulangi Gayathma Balasuriya[1,2], **Stig Irving Olsen**[1,2], **Michael Zwicky Hauschild**[2,1], **Mikołaj Owsianiak**[1,2]

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Environmental sustainability assessment and comparisons of products made from metals and plastics require consistent life cycle impact assessment methods to account for the use of mineral and carbon resources. Several new characterization models have been proposed in the past few years to account for mineral resource dissipation in life cycle impact assessment. However, accounting for the dissipation of the carbon resource is not that straightforward and lags behind. This study investigates the possibility of developing characterization factors for the carbon resource, building on existing dissipation-based characterization methods for mineral resources. For this purpose, we (1) collect existing models and characterization factors for mineral resources; (2) collect data and compute corresponding characterization factors using these models for the carbon resource; and (3) provide a critical appraisal of the new dissipation-based characterization factors for carbon. The findings highlight the need to account for dissipation mechanisms that are specific to carbon.

Session 1.09: Social Sustainability: Data & Method Advancements Part I

Time: Wednesday, 10/Sept/2025: 11:30am - 1:00pm
Session Chair: Luigia Petti, UNIVERSITÀ "G.D'ANNUNZIO", Italy
Session Chair: Sonia Valdivia, WRFA, Switzerland

Boycotting Congolese cobalt to improve social sustainability? Insights from a newly developed poverty reduction potential method

Rickard Arvidsson[1], **Julia Brunke**[1], **Anders Nordelöf**[1,2]

[1]Chalmers University of Technology, Sweden; [2]Swedish National Road and Transport Research Institute

Societal actors have considered boycotting cobalt from the Democratic Republic of the Congo (DRC) because of harsh social conditions. However, these conditions are largely symptoms of poverty, and how cobalt mining contributes to poverty has not yet been quantitatively assessed in a social life cycle assessment (SLCA) context. This SLCA study investigates the poverty reduction potential of the battery material cobalt sulfate produced in China from cobalt mined and refined in the DRC. Literature on poverty reduction and the cobalt sulfate life cycle were consulted to develop characterization factors (CFs) for poverty reduction potential. Considering the importance of economic growth for poverty reduction, the value added in processes constitutes the basis for the CFs. In addition, three factors that suppress the poverty reduction potential of economic growth were considered: corruption, inequality and the prevalence of poor people. These factors were accounted for by using the corruption perception index, the Gini coefficient and the share of people living below different poverty thresholds (2.15, 3.65 and 6.85 USD/day), respectively. The resulting poverty reduction potential reveals the product-related value added that may benefit the poverty-stricken population after corruption and inequality have taken their tolls. Our results show that the poverty reduction potential is higher in the DRC compared to China. This indicates that cobalt has the potential to reduce poverty in the DRC, although there may still be other barriers and local circumstances preventing this potential from being realized. Therefore, additional studies on the cobalt mining sector are recommended, considering for example the influence of Chinese ownership of the industry. Nevertheless, despite all uncertainties, it seems questionable that boycotting cobalt would have a mainly positive influence on the poverty and related social concerns in the DRC.

A Social Life Cycle Assessment Framework for Zero-tailpipe Emissions Vehicles: A Recommended Approach

Davis Jose, **Rose Nangah Mankaa**, **Marzia Traverso**

INaB-RWTH Aachen, Germany

This research introduces the Social Life Cycle Assessment (S-LCA) framework designed to evaluate the social impacts of Zero-tailpipe Emission Vehicles (ZEVs) throughout their entire lifecycle and developed through TranSensus LCA Project. Recognizing the growing importance of social sustainability, this framework aims to provide a comprehensive tool for assessing ZEVs' social footprint, from raw material extraction to end-of-life disposal.

Adhering to established standards like the UNEP 2020 Guideline and ISO 14075, the framework's development prioritized transparency, standardization, and inclusivity. A consensus-building approach, involving iterative discussions and voting, was employed to ensure robust and widely accepted recommendations. This methodology facilitated the refinement of crucial aspects, including establishing comprehensive system boundaries, defining functional units, and identifying relevant social impact subcategories across the

ZEV lifecycle.

The study successfully achieved consensus on key procedural elements for the four phases of S-LCA. However, it also acknowledged challenges inherent in social impact assessments, such as limitations in secondary data availability, confidentiality concerns, and the need for harmonization with environmental Life Cycle Assessments. These obstacles were addressed through careful consideration and strategic recommendations.

Ultimately, the proposed S-LCA framework serves as a practical tool for stakeholders to evaluate and enhance the social sustainability of ZEVs. By bridging the gap between theoretical frameworks and real-world applications, this framework provides a robust and adaptable method for integrating social considerations into the lifecycle analysis of ZEVs, promoting a more holistic approach to sustainable transportation.

Social LCA decision support for the safety and sustainability of nanomaterials

Jaakko Siltaloppi, Olga Dziubaniuk, Aki Jääskeläinen, Sikri Karhukorpi, Vilma Laaksonen

Tampere University, Finland

Decision making on the safety and sustainability of new materials and chemicals incorporates concerns over human health and increasingly environmental impact. However, social impacts are often left outside of such considerations apart from meeting minimum legal requirements. This study explores the utility of the social life cycle assessment (SLCA) method in informing product-related decision making, focusing on the assessment of social risks, such as workers health and safety, community welfare etc., associated with the production of promising new nanomaterial graphene oxide.

The study performs a comparative analysis of two scenarios for graphene production, adopting a reference scale approach that utilizes indicators and reference values in the Soca SLCA database. Data for the foreground system was collected from a European manufacturer and complemented with database sources. For the background system, Soca database was used.

The results show that background processes cause the majority of social risks. In addition, most significant social risks associated with the foreground processes are dependent on local/national conditions. In the advanced production scenario, reductions in waste generation and improved production efficiency result in significant reduction of social risks in most indicators used.

The findings highlight the value of SLCA for the identification of social risks across the value chain, which can steer decision making toward high-priority sustainability challenges. Simultaneously, the findings raise issues in the accuracy and utility of the results for company-level decision making. Based on the analysis, a multi-tiered approach for SLCA in product-related decision-making is proposed. First, specific indicators and performance reference points should be established at the company level to guide decisions on social impacts that can be directly influenced. Second, additional indicators at regional and national levels should be integrated to create a comprehensive basis for monitoring social performance and decision-making.

Socio-economic hotspots in the healthcare sector– A tailored social LCA (S-LCA) framework for healthcare devices

Sonia Valdivia[1], Loay Radwan[2], Camille Rønn[3], Federico Werner[4], Adrien Specker[4]

[1]WRFA, Switzerland; [2]GreenDelta; [3]ITU; [4]World Resources Forum

The healthcare sector significantly contributes to global resource consumption and environmental impact, generating 4-5% of CO2 emissions. Despite their convenience, the increasing use of single-use medical devices (SUDs) raises environmental, and socio-economic concerns.

This paper aims to examine socio-economic risks and benefits from a life cycle perspective, comparing SUDs with reprocessed devices (RDs).

The S-LCA method (UNEP, 2020; ISO 14075) is applied to SUDs and RDs focusing on suppliers, healthcare workers, patients and society. Life cycle stages include production, healthcare services and EoL.

Results:

- The UNEP (2020) framework was useful for identifying social hotspots, but adaptations were needed to cover health and safety (H&S) of patients and caregivers and promotion of social responsibility by producers. New impact categories include access to healthcare and H&S risks at EoL for local communities.
- The introduction of SUDs contributes to technological innovation while exacerbating negative social impacts of critical raw materials extraction.
- A disadvantage of reprocessing devices at hospitals is the increased workload requiring specialization e.g. on sterilization. However, RDs evidence low prices improving access to healthcare which is crucial for stakeholders with limited resources. For instance, pacemakers reprocessing costs amount to $60-$80, while new products cost above $1000s (Crawford et al., 2017). Surveyed physicians reported no issues with higher Infection rates (H&S) when applying RDs vs SUDs.
- The H&S risks at EoL for local communities arise from growing amounts of SUDs, particularly in poorly managed waste contexts.

Healthcare devices S-LCA results should be considered in procurement and medical procedure design decisions. Trade-offs between SUDs and RDs should be considered, with healthcare choices prioritized for population health and sustainability within planetary boundaries.

This study is part of the Digital Health in Circular Economy (DiCE) project funded by the European Research Executive Agency under the authority delegated by the European Commission (Grant Agreement No. 101060184).

Integrating Life Cycle Working Environment Methodology (LCWE) for Compliance with the Corporate Sustainability Due Diligence Directive (CSDDD)

Sharon Stauffert[1], Korbinian Czirwitzky[1], Rafael Horn[2], Matthias Fischer[3]

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The Corporate Sustainability Due Diligence Directive (CSDDD) introduced by the European Union, requires companies to assess and mitigate environmental and social impacts within their value chains to ensure responsible business practices. Currently companies lack adequate tools to implement these requirements, particularly regarding covering the entire value chain especially the practices of the upstream activities. In this context, the Life Cycle Working Environment (LCWE) methodology is an effective approach for asses-

sing social impacts throughout the entire value chain of a product.

The LCWE methodology is a quantitative, product-related assessment of social aspects directly building on and fully compatible with LCA. It is focusing on key issues such as labour rights, health, safety, and working conditions. It provides a social profile for products or product systems, with the ability to explore details down to individual process steps. The methodology currently comprises eleven indicators, including forced labour, child labour and the right to organise. Eight of these indicators are transferred to the requirements of the CSDDD. Furthermore, suggestions are provided for the integration of the remaining indicators to facilitate LCWE to be a suitable method for comprehensively covering the CSDDD guidelines along the entire value chain. This is done through reviewing alignment of LCWE with CSDDD and identification of the missing but compatible indicators.

By using the LCWE methodology, companies gain the ability to assess and report on social impacts in a structured and measurable way building on existing LCA models, ensuring transparency and accountability. It enables companies to identify risks and opportunities, mitigate potential negative impacts, and align their operations with the CSDDD. Ultimately, integrating of LCWE into decision making processes helps companies not only comply with regulatory frameworks, but also promote sustainable and responsible practices and sourcing throughout their entire supply chain, reinforcing their commitment to both social and environmental sustainability.

Addressing racial discrimination in Social Life Cycle Assessment: Indicators and reference scales

Isabel Susan Wolf, Lindsey Roche, Stella Unruh, Matthias Finkbeiner

Technische Universität Berlin, Chair of Sustainable Engineering (SEE)

Compared to its environmental and economic counterparts, S-LCA remains less widely applied due to the need for further development to comprehensively reflect social impacts and enhance its applicability, particularly within the broader LCSA framework. Racial discrimination, a pervasive societal challenge across diverse sectors and global supply chains, currently lacks sufficient representation in the S-LCA methodology. While the subcategory Equal Opportunities/Discrimination for the stakeholder Worker addresses some aspects, racial discrimination can occur at any point in the supply chain and affect various stakeholders, including Local Communities and Consumers. Cases spanning resource extraction, textile production, and medical practice, underline the need for S-LCA to address this issue more comprehensively beyond the Worker stakeholder.

This study provides practitioners with guidance on assessing racial discrimination, based on application-oriented examples from policy and industry. Key S-LCA guidelines were reviewed to evaluate the current state of the racial discrimination assessment and identify gaps within the methodology. Drawing on literature from various institutions (e.g., (non-) governmental organizations, industry associations or medical reports) presenting best practices or issues related to labour market access, working conditions, and the well-being of racialized minorities, we proposed performance indicators and subcategories for all affected stakeholder groups. These indicators were reviewed for applicability, relevance, and clarity by international experts in the fields racial discrimination and/or labour/organisational psychology. The indicators were then refined based on their feedback.

The final set of performance indicators, along with corresponding reference scales for each subcategory, are presented. They are intended to facilitate practical application and can be adapted to the product system under study. Future work will include applying these findings to industry case studies to evaluate their effectiveness and further refine the proposed framework. This work seeks to enhance the comprehensiveness of S-LCA, contributing to the broader integration of equity considerations into sustainability assessments.

Mapping Social Priorities: Engaging Stakeholders in Social Life Cycle Assessment

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With the recent introduction of the Corporate Sustainability Reporting Directive (CSRD), companies must disclose environmental, as well as social impacts, across their value chains. Social Life Cycle Assessment (SLCA) allows to quantify the potential social impacts of products, or services on different stakeholder groups. There are many prevalent indicators available, but not all are relevant for every company. To identify relevant topics for a specific case in a specific sectoral context, standardized methods are required. Central to identifying relevant social topics is the active involvement of affected stakeholder groups. Therefore, this study aims to support organizations in the pharmaceutical sector by identifying and prioritizing the most relevant social topics. In addition, a standardized approach for the identification and prioritization process is proposed, which can be adopted for other industries. In this study, a consultation process is conducted in three steps: (1) expert interviews to explore relevant social topics; (2) standardized survey to prioritize topics among experts in the industry, community representatives, academia, actors in the value chain of the product and potentially affected stakeholders such as consumers or local communities; and 3) a focus group workshop with actors from the pharmaceutical industry to verify the prioritization of topics. Preliminary results show that some topics are deemed more important than others e.g., safe and healthy workplace over social benefits. Besides the topics proposed in the European sustainability reporting standards (ESRS) and the UNEP guidelines on SLCA, experts from the industry identified additional relevant topics to be accounted for e.g., inequality in healthcare financing or transparency. To conclude, the stakeholder consultation process resulted in important methodological discourse and highlighted a list of prioritized social issues that should be considered in further reporting activities. In addition, a standardized approach for the identification process in a specific sectoral context is provided.

Prospective Pathways: A Social Life Cycle Assessment (LCA) Investigating the Potential of Green Hydrogen Production in South Africa

Taahira Goga, Valentina Russo

Council for Scientific and Industrial Research (CSIR), South Africa

South Africa faces a current challenge of securing clean, affordable, and sustainable energy to power its economy and transition to a carbon-neutral society. As the Just Energy Transition (JET) is not solely an environmental concern, addressing climate change holistically entails encompassing the economic aspects while considering the living condition and livelihoods of South African citizens. Although the South African government has identified hydrogen as a key priority area for the country, challenges lie in aligning the need for sustainable energy with the necessity for inclusive participation in this new sector. The aim of this study was to conduct a qualitative and quantitative prospective Social Life Cycle Assessment (S-LCA) of the South African hydrogen sector with a focus on the Saldanha Bay region. The qualitative assessment followed the Product Social Impact Assessment (PSIA) framework (Type 1 approach). Due to the prospective nature of the study as well as the macro-level scope, the methodology has been amended for the specific case study including the adaptation of the generic reference scale as well as an addition of a quantitative element. The assessment identified the local community as well as workers as significant stakeholder groups. The results generated were in the form of qualitative and quantitative indicators focusing on locally relevant social topics such as potential employment opportunities, skills development, and access to material and immaterial resources. Overall, the green hydrogen sector presents a combination of potential significant socio-economic opportunities and challenges in Saldanha Bay and in South Africa.

The outcome of the assessment highlights the significance of conceptualising low carbon development pathways within local contexts incorporating their own unique socioeconomic factors. Additionally, the analysis highlights linkages between the various social topics and emphasises that a systems-based approach is required.

Social sustainability in the motorcycle industry – a life-cycle perspective on the motorcycle supply chain

Melanie Arzberger

BMW Group, Germany

The importance to investigate sustainability in the automotive industry in general and the supply chain (SC) in particular is widely known. However, it needs to be discussed whether sub product group of the automotive industry, such as motorcycles, need a specific approach when analyzing sustainability.

The objective of this research project is to develop a motorcycle-specific approach to social sustainability along a product life cycle based on S-LCA, focussing on the supply chain.

Therefore, first the current state of S-LCA an in general social sustainability regarding motorcycles in the literature as well as its application in the industry will be analyzed. Next it is necessary to determine the typical structure of the motorcycle SC and its relevant stakeholders, which could be done with an expert survey and database calculations such as Social Hotspot Database and PSILCA.

This allows to collect relevant topics for an assessment of the social sustainability of a motorcycle life cylce, considering the relevant stakeholders and motorcycle-specific circumstances and also enables the definition and selection of indicators for measuring social sustainability of motorcycles.

Building on the previous steps, the goal is to determine, how the current subcategories and indicators can be applied for social sustainability assessment of the motorcycle SC and is further subcategories and indicators are needed. Therefore, the data availability is to be determined, possible challenges need to be identified and possible calculation options for an SLCA including mass and energy flows will be demonstrated by collection social data throughout the life cycle of a motorcycle/motorcycle component and/or other case studies.

Session 1.10: Sustainable mobility solutions Part I

Time: Wednesday, 10/Sept/2025: 11:30am - 1:00pm
Session Chair: Stephan Krinke, Fraunhofer IST, Germany
Session Chair: Jonas Wigger, MOIA, United States of America

"FutureCarProduction - A Life Cycle Engineering approach for sustainable Car body development"

Viktoria Rohwer, Zi Jun Lee, Stephan Krinke

Fraunhofer IST, Germany

In modern Battery Electric Vehicles (BEVs), environmental concerns have shifted from the usage phase (dominant in Internal Combustion Engine Vehicles, ICEVs) to batteries and Body-in-White (BIW) production. In the cradle-to-gate Life Cycle Assessment of BEVs, BIW has the second largest carbon footprint after the battery. Conventional BIW production involves welding over a hundred stamped metal parts, a resource-intensive process. Aluminum gigacasting offers a transformative alternative, enhancing efficiency, reducing scrap, and lowering energy consumption. Whereas Aluminum has been classified by the EU as a strategically important and critical material, strategic initiatives are in place to facilitate a reduction in the environmental impact of aluminum production. Similarly, other competing material solutions such as low carbon steel or multi-material BIW structures also offer environmental benefits.

To support Original Equipment Manufacturers (OEMs) regarding these factors in transitioning towards zero-emission goals, the Fraunhofer flagship project "FutureCarProduction" is developing methods and technologies for sustainable automotive body construction. Guided by an industry advisory board covering OEMs and first-tier suppliers to assure that the developed Life Cycle methods can be directly applied in product development processes, and encompasses eight Fraunhofer institutes. This comprehensive approach identifies ecological hotspots such as material supply and energy use, providing actionable insights for integrating sustainability into product development.

The LCE tool aligns automotive components' environmental impacts with science-based targets, enabling quantifiable carbon reduction at the component level. Marginal Abatement Cost Curves (MACC) further support cost-efficient decarbonization by quantifying avoidance costs (€/t CO_2eq avoided) and ranking interventions for optimal environmental and financial outcomes. This approach empowers automotive companies to meet the Paris Climate Agreement's 2°C target, embedding sustainability directly into their operations. By integrating life cycle insights with innovative technologies, the FutureCarProduction project demonstrates how sustainable automotive innovations can be both achievable and economically viable.

Comparative assessment of mineral resources dissipation, criticality and depletion methods in LCA for the automotive industry: A case study

Jair Santillán Saldivar[1], Gladys Moreac-Njeim[2], Lauran Van Oers[3], Takunda Chitaka[4,5], Anish Koyamparambath[4,5], Guido Sonnemann[4,5], Davis Jose[6], Antoine Beylot[1]

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The electro-mobility sector represents a key industry for the energy transition; zero emission vehicles are regarded as a vital technology to support decarbonisation. However, the increased use of metals and minerals for batteries and charging infrastructure remains a challenge for the adoption of electric vehicles. The current practices in life cycle assessment (LCA) focus on resource depletion to quantify the impacts of human activity on mineral resources availability. Raw material criticality and resource dissipation have been introduced as novel concepts to address the missing methodological aspects in the assessment of abiotic resources.

This contribution aims to compare and interpret the results of the application of depletion, criticality and dissipation methods to an industrial case study on an electric vehicle. Four methods were tested: Abiotic Depletion Potential (ADP), the default method to assess natural resources based on geological availability; Geopolitical Supply Risk (GeoPolRisk), introduced in LCA to assess raw material criticality; Environmental Dissipation Potential (EDP), proposed as a long-term analysis of resource losses from the technosphere; and Average Dissipation Rate (ADR), designed to study the use of fast-dissipating resources.

Results show hotspots based on the methodological questions behind each method. ADP highlights gold and cobalt as contributors due to their relative scarcity; GeoPolRisk assigns a higher share of impacts to critical materials present in magnets and batteries (e.g. rare earths, cobalt, lithium). ADR underlines rare earths due to their losses in early stages of the supply chain; and EDP highlights nickel, silver and cadmium as highly traced emissions in the vehicle supply chain.

Diverse results for each method indicate a potential complementarity for impact assessment of abiotic resources use in LCA. Specifically for the automotive industry, their mainstream use could show impact transfers associated to new battery chemistries, improvements in performance, among other relevant aspects for decision-making processes in the sector.

Life Cycle Assessment by Powertrain Using Big Data for the Optimization of Environmental Impact by Country

Keisuke Sano[1], Tamaki Ozawa[1], Sayaka Kakiuchi[2], Norihiro Itsubo[2]

[1]Toyota Motor Corperation, Japan; [2]Waseda University, Japan

The need for environmental impact assessments of climate change and other factors over the life cycle of products has come to be questioned, and assessments are now being made for automobiles as well. However, the current situation is that all gasoline-powered vehicles and BEVs are being assessed with the same lifespan and the same driving distance, and this does not reflect how they are actually used in the market. Therefore, we used big data from Japan and the US to analyze the diverse ways in which customers in each region use their vehicles. By classifying customer trends such as vehicle utilization rates, distance driven per day, average vehicle speed, and frequency of long-distance driving, and comparing and analyzing environmental evaluations based on each usage pattern, we can study what powertrain specifications are most environmentally optimal for each type of customer. By using this method, we can not only evaluate environmental impact more accurately, but also quantify the potential market share in each region for powertrain specifications that are environmentally optimal for each individual customer. There are also significant differences in the way cars are used in different regions, such as Japan and the United

States, and this can be shown quantitatively to affect the potential market share of environmentally-optimal powertrains. As these trends also change with the times, it is also important that the results of LCA research are fed back into the development of each powertrain.

Reducing Environmental Impacts in Electric Mobility through Next-Generation Battery Technologies

Abhishek Khairnar, Dr. Denise Ott, Levin Winzinger, Daniel Habermeier

EurA AG, Germany

Sustainable battery technology is essential for the global transition to clean energy, reducing environmental impacts, and ensuring resource efficiency amid growing energy demands. This presentation evaluates the environmental footprint of emerging battery technologies, specifically solid-state batteries (SSBs) and sodium-ion batteries (SIBs), which could partially replace lithium-ion batteries (LIBs) in the electric vehicle market. Given the rising demand for batteries in mobility, adopting a systems-based approach to assess their environmental impacts is crucial. This helps identify areas for improvement and supports the creation of policies to minimize their environmental footprint.

Solid-state batteries are the next generation of batteries for electric vehicles, offering enhanced safety and higher energy density compared to conventional LIBs. This research examines their lifecycle environmental performance, focusing on potential reductions in greenhouse gas emissions, resource depletion, and energy consumption. Using an LCA framework, the study demonstrates how SSBs can advance sustainability in electric mobility.

Initial screening analysis identifies ecological hotspots early in the LCA process. Comparative LCA is conducted with state-of-the-art and reference systems (LIBs) to highlight the ecological advantages of newly developed processes and products. Additionally, the study assesses the direct recycling of cathode materials from LIBs into sodium-ion batteries as a strategy to address critical material reliance and waste generation. This innovative approach reduces demand for virgin materials and extends the lifespan of valuable resources, contributing to a circular economy. By leveraging project data and literature, this analysis underscores the environmental potential of both SSBs and direct recycling technologies, demonstrating their role in promoting sustainable electric mobility.

Projects FUNCY-SSB (03XP0616C) and LIB2SIB (03XP0617B) were selected in the Joint Transnational Call 2023 of M-ERA.NET 3, which is an EU-funded network of about 49 funding organisations (Horizon 2020 grant agreement No 958174). The projects FUNCY-SSB and LIB2SIB are funded by the Federal Ministry of Research, Technology and Space (BMFTR), Germany.

Life Cycle Assessment of Waste Transportation Scenarios: A Case Study in Austrian Winter Sport Industry

Majid Tabatabaei, Ulrike Kirschnick, Ewald Fauster

Montanuniversität Leoben, Austria

End-of-life (EoL) waste management is considered as one of the core elements in the transition to a circular economy (CE) since it increases resource efficiency and can contribute reducing harmful impacts on the environment. In general, EoL management includes the collection and transportation of post-consumer waste products, the separation of materials, recycling and reprocessing them to supply into production.

The winter sports industry has a similar structure and faces similar challenges with post-consumer good circularity as other industries in the European context. Recycling the rather complex hard goods with multiple polymer-based materials as one of the major contents of these products would be a key strategy to

closing material loops.

The suitability concerning environmental performance of various end of life management techniques and processes needs to be evaluated by the use of sustainability assessment (SA) tools, such as Life Cycle Assessment (LCA).

In this work, scenarios under two different transportation modes for the collection of used winter sport equipment from the users are examined:(1) utilizing existing retailer logistics networks for take-backs, and (2) using municipal transportation routes to deliver waste to urban recycling centers. Realistic data from current practices and newly established collection routes are collected to reflect on the system functionality within current Austrian framework conditions.

Within the framework of these scenarios, a comparative LCA was performed focusing on five hard good categories (skis and bindings, helmets, boots, and poles) in an Austrian model region, particularly dedicated to winter sports sector. Data on distances, logistic networks, vehicle specification, and carried volumes have been integrated into the life cycle inventory (LCI) of these use cases. Using Environmental Footprint Life Cycle Impact Assessment (EF LCIA) methodology, the effect of various factors such as load capacity, vehicle return condition, collection frequencies and system management on ecological burdens were analyzed.

Life-Cycle Assessment of Municipal Mobility in the Czech Republic - Focus on FCEV

Jiri Stefanica[1], Marek Carbol[2], Ales Paulu[3], Jan Fiser[4]

[1]UJV Rez, a. s., Czech Republic; [2]Transport Research Centre, Czech Republic; [3]University of Chemistry and Technology Prague, Czech Republic; [4]Brno University of Technology, Czech Republic

This contribution presents the main results of a 3-year project "CK04000045 Life-Cycle Assessment of vehicles". The main goal of the project is to provide the Ministry of Transportation with relevant data regarding the environmental impacts of municipal mobility with different motorizations. The results will be used to enhance the efficiency of public support aimed at personal mobility with regard to decarbonization efforts. The study focuses on different categories of road vehicles used in municipal areas - passenger cars, cargo vans, light freight cars (12,5 t) and buses. Each category is examined with different motorisations (if applicable) - gasoline/diesel, battery-electric, fuel-cell-electric (hydrogen), hybrid, CNG. The analysed life-cycle includes vehicle construction, operation in municipal areas and EOL. All methodological choices reflect current and expected conditions of the Czech Republic. Special focus is given to analysing the fuel-cell-electric-vehicles (FCEV) using different types of hydrogen.

Well-to-Wheel greenhouse gas emissions of battery electric vehicles considering temporal variability: A South Korean case study

Juha Lee, Inyoung Ko, Wonjae Choi

Ewha womans university, Korea, Republic of

Conventional Well-to-Wheel (WTW) analysis of battery electric vehicles (BEVs) typically presents a single value using the average power generation mix for a specific year and official fuel economy. However, the factors involved in calculating the WTW greenhouse gas emissions for BEVs vary depending on temporal parameters. This study evaluated the WTW greenhouse gas emissions of BEVs by considering temporal variability in factors such as power generation mix, ambient temperature, battery degradation, and charging speed. South Korea was selected as the region of analysis. The GREET program, developed by Argonne National Laboratory in the United States, was adapted and expanded to reflect South Korean conditions.

GT-SUITE, a simulation software developed by Gamma Technologies in the United States, was used to create an EV model for analyzing changes in fuel economy according to temperature. For battery degradation and charging speed analysis, GT-AutoLion was used for lithium-ion battery modeling. The WTW GHG emissions for BEVs in 2022, without considering temporal variability, were 112 g-CO2-eq./km. The study confirmed that when considering temporal changes in the power generation mix, the highest WTW emissions were 8.7% higher, and the lowest emissions were 33% lower than the value calculated without considering temporal variability. When temporal changes in ambient temperature were considered, the maximum WTW GHG emissions were 71% higher than those calculated without accounting for temporal variability. Moreover, when battery degradation was considered, the WTW emissions significantly increased after 11 years of use, and after 15 years, emissions were 6.1 % higher compared to the time of purchase. Finally, quick charging of battery electric vehicles resulted in 2.8 % higher WTW GHG emissions compared to standard charging.

Life cycle assessment of production and recycling of materials in e-motor used in transport for passenger cars

Jannatul Ferdouse, Simone Ehrenberger

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The transportation and automotive sectors are shifting toward electric vehicles to lessen the effects of global warming. Manufacturing of electric motors is an essential component of the powertrain produced from resource-intensive raw materials and rare earth elements (REE). This study evaluates the material-level life cycle assessment (LCA) effects of e-motor manufacturing and recycling, encompassing motor, rotor, stator, and permanent magnet manufacture and recycling. The system boundary involved the production of subcomponents such as the housing, shaft, magnet, and steel from primary sources, followed by the assembly and disassembly of these subcomponents, and the sorting of ferrous and nonferrous materials for recycling. The study employs the ReCiPe 2016 v1.03, midpoint (H) methodology as its life cycle assessment approach. The results indicate that rotor manufacture has the most substantial influence (50.58%) owing to the incorporation of permanent magnets (PMs). Manufacturing of steel and aluminum significantly impacts the housing production phase. We covered the essential stages of recycling, including manual sorting, size, magnetic separation, and x-ray sorting. The process of magnetic separation yielded 34.2 kg of non-ferrous metals and 69.8 kg of ferrous materials (such as steel and PMs), which significantly influenced the manufacturing of rotors due to the presence of rare earth elements (REEs). The recycling process eliminates the initial production pathway, resulting in energy savings of up to 33 kWh/kg during primary phases, including the extraction of oxides and the reduction of pure elements. Disassembled aluminum is one example of a recycling process that produces 94.7% fewer emissions than primary manufacture. The recycling pathways for steel, copper, brass, and magnets also reduce emissions. Each metal or sub-component has different degradation or recycling rates, which affects the product's composition and lifespan. However, the extensive usage of non-renewable technology and equipment requires sustainable energy sources for production and recycling.

Session 1.11: Circular Textiles: how LCA can Support the Transition

Session Chair: Archana Datta, UNEP, France

Session Chair: Claudia Giacovelli, UNEP, France

Panel discussion

Session 1.12: Healthcare LCA

Time: Wednesday, 10/Sept/2025: 11:30am - 1:00pm
Session Chair: Rose Nangah Mankaa, INaB-RWTH Aachen, Germany
Session Chair: Scott McAlister, University of Melbourne, Australia

Application of LCA for Pharmaceuticals: Lessons from a Ten Year Programme in AstraZeneca

Aoife Calnan[1], Hugh Whetherly[1], Donald Reid[1], Michael Collins[1], Simon Aumônier[2], Andy Whiting[3], Chloë Smithers[3]

[1]ERM, United Kingdom; [2]Aumônier Consulting, United Kingdom; [3]AstraZeneca, United Kingdom

AstraZeneca's life cycle assessment (LCA) programme now covers approximately 90% of its product portfolio by revenue, with LCA studies being updated at a frequency appropriate to capture changes. This comprehensive coverage across various therapy areas and administration routes allows for broad conclusions to be drawn and identification of key drivers of impact across pharmaceutical modalities. The programme highlights the importance of collecting specific primary data, the utility of LCA in developing reduction strategies, and its role in enhancing the accuracy of Scope 3 reporting while tracking process improvements over time.

Each product in AstraZeneca's portfolio which is appraised receives an internal Product Sustainability Index (PSI) score which is used to prioritise environmental sustainability improvements at the product level. The results of LCA studies also support holistic assessments of the full care pathways in which the medicines are utilised. Some studies explore reduction options, such as: manufacturing sites sourcing renewable electricity and heat; increasing yields and process efficiencies; and recovering waste solvents. These insights help pinpoint critical areas for sustainability policy development and lead to the reduction of the environmental impacts of pharmaceutical manufacturing and medicine use, thereby contributing to a more sustainable future.

An LCA of knee reconstruction surgery

Scott McAlister[1,2], Forbes McGain[1,3], Kasun Kasun Wickramarachchi[3]

[1]University of Melbourne, Australia; [2]University of Sydney, Australia; [3]Western Health, Melbourne, Australia

Over 313 million surgeries occur annually around the world. While there have been a small number of LCAs undertaken on surgery, each has excluded important aspects such as operating theatre heating, ventilation, and air conditioning (HVAC) or the washing and sterilization of equipment. We therefore undertook an LCA encompassing all emissions sources associated with a knee reconstruction (TKR). We chose TKRs because they are expected to increase by 7% annually as populations age, and compared to other common surgeries use a considerable amount of equipment.

We examined 10 elective TKRs in an Australian public hospital. The weights and compositions of all reusable and single-use surgical equipment (e.g. trays, forceps, drills, material cement etc) was recorded, as was other consumables such as bandages, towels and surgical drapes, and the knee prothesis itself. Data for anaesthesia, including the quantity of all the drugs delivered along with all equipment and consumables used to deliver the anaesthesia, was obtained from 3 groups of 10 patients (general, spinal, and combined spinal and general anaesthsia). The energy used by the operating room's (OR) HVAC, was modelled using TRNSYS building energy simulation using data (e.g. air flow rates, supply/return temperatures, humidity etc) obtained from an OR combined with annual weather data (e.g. hourly average solar radiation, outdoor

air temperatures etc).

The average carbon footprint was 131.7 kg CO2e, with the main source of emissions being the energy used to steam sterilise the surgical sets (33%) and the single-use equipment (26%). Anaesthesia and OR energy contributed 11% and 9% respectively.

Environmental impact of a population-based cancer screening programme

Lieselot Boone[1], Jo Dewulf[1], Bente Verhaegen[2], Janne Dhondt[2], Hyemin Lee[1], Katrien Vanthomme[2], Lisa Van Wilder[1,2], Margot Cooreman-Algoed[1], Delphine De Smedt[2]

[1]Department of Green Chemistry and Technology, Faculty of Bioscience Engineering, Ghent University, Ghent, Belgium; [2]Department of Public Health and Primary Care, Faculty of Medicine and Health Sciences, Ghent University, Ghent, Belgium

The healthcare industry aims to improve and maintain the health of patients, but this comes with a significant contribution to the global carbon footprint. In the quest to reduce environmental impact, it is important to adopt a systems perspective when evaluating environmental sustainability, i.e. considering the entire healthcare pathway; in particular relevant when analysing screening programmes.

This case study focuses on the population-based cancer screening programme in Flanders, which aims to detect colorectal cancer at an early stage, enabling early and adequate treatment hence reducing disease burden and cancer-related mortality. Many studies investigated the health benefits associated with cancer screening programmes, as well as the cost-effectiveness. However, little is known about their environmental impact.

Life cycle assessment (LCA) is used to quantify the environmental impact of colorectal cancer screening in Belgium, covering both the initial screening phase and any subsequent treatments. The results are then compared to the scenario in which no population-based cancer screening program is in place (i.e. opportunistic screening or when symptoms occur).

As a first step, a comprehensive overview of the patient care pathway is created, outlining the activities that compromise the value chain of care provision, including the various tasks related to screening, diagnosis and treatment. The next step is to identify the material and energy needs at each stage of the care pathway, allowing for the calculation of environmental impacts per step, and ultimately determining the impact of the Flemish screening program.

LCA results help identify the hotspots of considered screening program. Next, this study highlights the importance of adopting a systems perspective in sustainability assessments that encompass the entire healthcare pathway. Only through this approach can a fair analysis of the impact of screening programs be achieved. A follow-up phase will balance this outcome against health outcomes and healthcare costs.

A comparative environmental sustainability assessment of different schizophrenia treatment options

Lotte Neckebroeck[1], Lieselot Boone[1], Lisa Van Wilder[1,2], Delphine De Smedt[2], Wouter De Soete[3], Bert Verstappen[3], Amr Makady[3], Bert Heirman[3], Jo Dewulf[1]

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The main goal of the healthcare sector is to enhance and ensure patient health. However, in pursuing this goal, this sector contributes significantly to the global carbon footprint. Therefore, pharmaceutical companies are increasingly focusing on reducing the environmental footprint of the production of their medicines. Nonetheless, a comprehensive sustainability evaluation is required to fairly compare the impact of different pharmaceuticals and corresponding treatment. However, modelling the use phase is challenging, given the often complex care pathway and associated consumption profile.

The objective of this work is to analyze and compare the environmental impact of four treatment options for schizophrenia. No treatment will be compared with standard care (one-monthly injections) and two different types of long-acting injectables, all considered for five years of treatment in Belgium.

As a first step, the different health states experienced by patients during treatment will be defined in a Markov model. This Markov model with its transition probabilities will result in an overview of the patient's distribution across health states, and by extension which healthcare pathway elements are used per treatment (e.g. number of injections and GP visits, or length of hospital and psychiatric stay).

In a second step, a life cycle assessment will be conducted to quantify and compare the carbon footprint of these four treatment options. The ReCiPe midpoint (H) method will be used for impact assessment, using primary data retrieved through collaboration with a pharmaceutical company. Furthermore, key life-cycle stages and parameters over the treatment will be identified.

This case study will demonstrate the need to expand environmental sustainability assessments beyond the pharmaceutical supply chain. Incorporating the entire care pathway will enable a more comprehensive environmental sustainability evaluation of drug products.

The need to make surgical placement practices more circular for dental implants: Results from a Life Cycle Assessment study

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The healthcare sector is an area of increasing interest in the Life Cycle Assessment community. In particular, the sector accounts for approximately 5% of global greenhouse gas emissions. With 3.5 billion people suffering from oral diseases, dentistry plays an important role in public health. Technical progress has continued to push forward, including the ability to implant new prosthetic teeth in the mouth. However, it comes at an environmental cost.

This study is the first to assess the environmental impacts associated with the manufacture and placement of a titanium based dental implant. Data for ore extraction was collected from literature and databases and manufacturing data from the Brånemark Integration company. Implant placement data was collected in the hospital of Montpellier (France).

The majority of impacts can be attributed to placement of the implant whilst the extraction and manufacture of the implant itself contributed minimal amounts. The global warming impact of dental implants is significant. Placing an implant would represent the equivalent of driving 142 km with a combustion-powered car sold in 2020 in France. This impact is mainly due to the manufacturing and disposal of single-use

medical devices to perform the procedure. Further, 2.5 kg of waste is thrown away, of which 1.8 kg is plastic. The sensitivity analysis reveals a link between circular economy modulation and results variations, where recycling reduces up to 15% of impacts. However, reusing materials resulted in important impact transfers and negative impacts overall on the system.

From our results, we have learned that there is a clear need to make surgical placement practices more circular. This needs actions at multiple levels combining public policy-making, hospital management and individual motivation.

Integrating ecodesign at a supplier for the biopharmaceutical industry

Alexander Kaluza, Jannis Schliesing

Sartorius Lab Instruments GmbH & Co. KG, Germany

The biopharmaceutical industry plays a pivotal role in enhancing drug development and manufacturing, thereby contributing to improve global health and well-being. The corresponding product portfolio needed ranges from single-use laboratory consumables, systems & instruments to media & reagents. The industry lacks a long-standing tradition of integrating environmental sustainability in its processes and products, as the transition towards integrating sustainability is influenced by specific boundaries. For example, this includes sterility and cleanliness of products after manufacturing, a strict certification and regulatory environment, customized laboratory instruments with small quantities, and contamination of products at their end of life. Furthermore, the standardization of sustainability assessment and reporting methodologies along the value chain is still underway.

Sartorius is a key supplier to the biopharmaceutical industry and has set itself ambitious sustainability targets, such as the integration of ecodesign & circularity into its product portfolio. Therefore, Sartorius has developed a five-step process to enable life cycle thinking right from the beginning of product development. This process encompasses the early assessment of innovation ideas, the definition of clear sustainability requirements, the application of LCA during concept & design phases and the documentation of sustainability features. Albeit the diverse challenges, several solutions to improve environmental sustainability exist. This includes efficiency gains for laboratory instruments, sustainable material feedstocks and optimized designs for single-use consumables, reusability options, lyophilized media, and disruptive process innovations through digitalization.

The value of this approach lies in integrating environmental sustainability from the early stages of innovation and exploring opportunities for the biopharmaceutical industry. By implementing ecodesign principles, utilizing LCA for decision-making, and documenting sustainability features, Sartorius shift its portfolio towards sustainable innovation, meeting the evolving demands of the industry and its customers.

Scaling Innovation in Scope 3 Reporting: Supplier-Specific Data for Purchased Goods

Aoife Calnan[1], Doyin Oladele[1], Saori Galley[1], Simon Aumônier[2], John Basbagill[3], Hugh Whetherly[1], Jessica Vieira[3]

[1]ERM, UK; [2]Aumônier Consulting, UK; [3]Takeda, USA

Accurate Scope 3 greenhouse gas (GHG) accounting remains a critical challenge for companies with complex supply chains. Reliance on generic emission factors, such as those derived from environmentally extended input-output (EEIO) models, often results in significant uncertainty for Category 1 (purchased goods and services) Scope 3 accounting. This paper presents Takeda's approach to enhancing the precision of Scope 3 GHG reporting by transitioning from EEIO-based methods to scalable, supplier-specific

emission factors.

Since 2018, Takeda has advanced its Scope 3 methodology by incorporating life cycle thinking and hybrid approaches. In 2024, Takeda launched a pilot study to assess two novel methods for integrating supplier-specific data into its carbon accounting framework. The first method estimates emissions using supplier-reported Scope 1, 2, and 3 data, adjusted for supplier revenue and Takeda's purchasing spend. The second method uses the ecoinvent database to develop emission factors that reflect suppliers' renewable energy use, informed by reported supplier renewable energy sources.

The pilot evaluates these methods against traditional activity-based and EEIO approaches, focusing on scalability, uncertainty management, and future reporting needs. The resulting framework is designed to scale to many suppliers, with this year's study targeting an initial cohort of up to 50 suppliers.

This paper highlights the transformative potential of integrating supplier-specific data into corporate carbon accounting systems, offering a scalable and replicable pathway for more accurate Scope 3 emissions reporting. The proposed methodology promotes standardized, data-driven practices that can be adopted across industries. Additionally, supplier engagement fosters dialogue on data-sharing practices and encourages collaboration within and beyond the pharmaceutical sector. By presenting this innovative approach, the study lays the foundation for refining and advancing Scope 3 accounting methodologies.

Diagnosing sustainability: A bottom-up organizational life cycle assessment of a maximum-care university hospital in Germany

Lukas Messmann[1], Johannes Zobel[1], Felix Assies[1], Sandra Köhler[1], Alex Cimprich[2], Steven B. Young[2], Renate Linné[3], Andrea Thorenz[1], Axel Tuma[1], Miriam Köhler[1]

[1]University of Augsburg, Germany; [2]University of Waterloo, Canada; [3]University Hospital Augsburg, Germany

Hospitals are facing increasing pressure to adopt sustainable practices. A critical aspect of this transformation involves quantifying and reporting environmental impacts. Unlike top-down spend-based methods, bottom-up organizational Life Cycle Assessment (O-LCA) offers a detailed perspective on multiple environmental effects, including but not limited to global warming. This study evaluates the annual environmental impacts of a 1700-bed university hospital in Germany for 2021, 2022, and 2023. The assessment encompasses the hospital's inputs and outputs, including energy and water use, direct emissions from fuel and medical gases, transportation, travel, laundry, procurement (e.g., food, pharmaceuticals, or medical supplies), and waste and wastewater generation. A robust Life Cycle Inventory combines primary data and supplementary background data from ecoinvent 3.11 and AGRIBALYSE 3.1.1 with a sampling approach similar to a recent O-LCA study on a Canadian hospital. We explore the full set of environmental impact categories (with, i.a., EF3.1, ReCiPe 2016, and USEtox), with a special focus on climate change and DALY, and derive societally borne, external costs. The findings are compared with those of similar studies as well as spend-based top-down approaches. The analysis identifies procurement, energy, and waste as principal hotspots, providing guidance for the hospital's sustainability strategy. The study further contributes to the current discussion on top-down vs. bottom-up and spend-based vs. product-based approaches and advances the quality and scope of LCA in healthcare.

Life Cycle Assessment of Blood Glucose Measurement: Self-monitoring vs. Continuous Monitoring

Aida Hosseinian, Annika Johansson, Jaakko Karvonen, Ari Nissinen, Atte Pitkänen, Laura Sokka

Finnish Environmental Institute (SYKE), Finland

This study evaluates the environmental impacts of two prevalent blood glucose measurement methods for diabetes management: self-monitoring of blood glucose and continuous glucose monitoring systems. Main components and materials of six devices including both techniques were disassembled and weighed. The different plastics were identified using Fourier-transform infrared spectroscopy (FTIR). A cradle-to-grave life cycle assessment was performed to comprehensively evaluate the environmental impacts of these devices, across all midpoint impact categories (using method ReCiPe). The results indicate that self-monitoring devices generally have lower environmental impacts compared to continuous glucose monitoring devices across all midpoint categories, except for land use and mineral resource scarcity. However, if the self-monitoring method involves a higher-than-normal testing frequency, or the glucose meter device has a shorter than average lifespan, its environmental impact can increase significantly, and for most of the devices it can be comparable with continuous glucose monitoring. The primary contributors to environmental impacts of self-monitoring devices are strips and lancets, while in continuous monitoring systems, plastic materials and instruction leaflets account for a significant share of environmental impacts. This research provides important insights for product manufacturers, policymakers, healthcare providers, and individuals with diabetes, supporting more environmentally conscious choices in diabetes care technologies. While this study has a broad scope of multiple environmental categories, it should be acknowledged that there are other factors such as medical needs, economic incentives, and convenience which can significantly influence product selection

LP1: Lunch & Poster

Time: Wednesday, 10/Sept/2025: 1:00pm - 2:00pm

Challenging the sustainability of packaging designs: Life cycle assessment of paper vs. plastic fruit trays in the context of a circular economy

Hannah Köhler, Rosalie von Behr, Alena Maria Spies, Kathrin Greiff

RWTH Aachen, Germany

The discourse on sustainable packaging has gained importance in recent years due to consumer perceptions of sustainability and evolving legal regulations. On the one hand, sustainable images have led to a notable shift from plastic to paper-based packaging. However, considering the significant energy and water consumption, and land occupation of the paper industry, it is essential to assess whether paper packaging offers environmental benefits compared to plastic alternatives, particularly regarding end-of-life considerations.

On the other hand, legal regulations on circular economy focus on achieving high recycling quotas and increasing the share of recycled materials (recyclates) in products. Since recycling processes can be resource- and energy-intensive, it must be assessed whether these regulations are reasonable and environmentally beneficial. Additionally, the availability of recyclates may be limited due to material losses during processing. Therefore, an evaluation of the recyclability of packaging is essential.

To investigate how material selection and recyclability impact the environmental performance of packaging, we conducted a life cycle assessment (LCA) comparing fruit trays made of paper, paper composite, and plastics from both primary and secondary materials. Our analysis focused on four key impact categories: global warming potential (GWP), cumulative energy demand (CED), water consumption potential (WCP), and land occupation potential (LOP). Additionally, we quantified the potential recycling rates for each packaging system.

Results indicate that the environmental impact of fruit trays highly depends on the recycled content. Increasing the amount of recyclate in trays can reduce impacts across all assessed systems. However, limitations in recyclability constrain achievable amounts of recyclate and thereby the reduction of environmental impacts. Regarding packaging materials, paper and paper composite trays show lower impacts for GWP, CED, and WCP but higher impacts for LOP compared to plastics.

These insights are crucial for informed decision-making on sustainable packaging design and legislation promoting environmentally sound practices.

Environmental Impact and Fire Risk Assessment for Lithium-ion Battery

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While lithium-ion batteries are highly convenience, they also have several problems. The first is that lithium-ion batteries have a large environmental impact. Lithium-ion batteries use many rare metals, and the environmental impact of mining and refining is significant, so they must be recovered and recycled. However, current recycling technologies have a large environmental impact, and new of them are being considered to reduce it. The second is that lithium-ion batteries have a fire risk. Lithium-ion batteries have a risk of fire during their life cycle, and in particular, fires caused by contamination of waste treatment facilities are on the rise. Therefore, sorting technology to prevent contamination of lithium-ion batteries is being considered. This study will evaluate the environmental impact and fire risk for small lithium-ion batteries. The environmental impact and fire risk of the current process will be quantitatively evaluated, and the reduction of them will be quantitatively evaluated when the latest recycling technology and technologies to prevent

contamination are introduced. For the environmental impact, in addition to the greenhouse gas emissions during the life cycle of the lithium-ion battery, the reduction of them when the latest recycling technology is introduced and the reduction of resource consumption by recycling materials will be focused on. For fire risk, in addition to the probability of fire and the degree of damage during the life cycle, the effect of reducing the contamination rate by using the latest sorting technology will be focused on. Through this research, I would like to contribute to the construction of a safe recovery system for lithium-ion batteries.

Life Cycle Environmental Impacts of Alternative Recycling Processes for Textiles

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Textile production is continuously expanding and involves the use of raw materials, water, and soil. The mitigation of environmental impacts of the sector and the recycling of textile materials are fundamental building blocks for sustainability. Life Cycle Assessment (LCA) applied to the circular economy can give a substantial contribution to sustainable development because they allow the environmental impacts of a product's entire life cycle to be assessed. The application of LCA to the circular economy, however, is characterised by critical issues related to modelling choices like system boundaries, allocation, but also the valorisation of secondary raw materials. These already known problems, are insufficiently regulated by standards and guidelines. The article aims to investigate how the quality of the secondary raw material is significant in assessing the environmental impact of recycling processes through an LCA analysis. Upcycling or downcycling case studies are compared to verify the environmental performance of different uses of textile waste. In particular, the article assesses the environmental impacts of recycling process as upcycling in the same sector, to produce additional tissue, and a downcycling characterised by the transfer of waste to another industrial sector (e.g. to produce insulation board useful for the building sector). It is expected that in the case of upcycling the waste maintains its value and consequently that LCA enhances this type of process in contrast to cases where the recycling is a downcycling. LCA results may not clearly show the convenience of using textile waste for upcycling instead of downcycling and this may be a limit of the LCA methodology that will be discussed.

This study was carried out within the MICS (Made in Italy – Circular and Sustainable) Extended Partnership and received funding from Next-GenerationEU (Italian PNRR – M4 C2, Invest 1.3 – D.D. 1551.11-10-2022, PE00000004).

Integrating Life Cycle Assessment into decision-making tools for reuse & digital innovations in WEEE management

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ecosystem is a Producer Responsibility Organization (PRO) accredited to organize and manage the collection, the repair, the reuse and the recycling of Waste of Electrical and Electronic Equipment (WEEE).

Bonded to new responsibilities with the "Anti-waste law for a circular economy", enacted in France in 2020, ecosystem has been working on the development of new tools to promote the extension of product lifespan and circularity by assessing environmental impacts and benefits through LCA and product lifetime modeling. The assessment is based on a comparative approach between a replacement scenario and a reuse scenario over a period of product lifetime extension.

Overall, calculations have shown significant environmental benefits of reuse and optimized with a longer period of extension. Yet there are some limitations to guarantee the reuse and to ensure an environmental

benefit over a replacement scenario: product's age, spare parts needed, 2nd lifetime potential. For instance, the average reuse scenario of an old refrigerator shows higher impacts than a replacement. Thus, it questions the decision to either extend a product's lifetime, or to send it to recycle.

A digital tool using AI has then been developed to better diagnose the reuse potential of a product based on relevant information (manufacturing date, energy consumption, etc.) obtained from simple scanning. Besides the technical feasibility of reuse and economical interest, the environmental assessment is planned to be integrated into the tool as a support of the decision-making.

Finally, the Digital Product Passport (DPP) regulation being enacted by the European Commission is aimed at more product traceability and circularity. ecosystem and some of its stakeholders are currently conducting an experimentation of a blockchain-based tool to improve the traceability of household appliances through their entire lifecycle as an anticipation of the DPP, with the consideration of the environmental assessment at a product level.

Clear communication on the environmental benefits of animal feed products

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This session will explore a case study showcasing the validation of circular economy practices through Life Cycle Assessment (LCA) applied to two innovative animal feed products, Maxy Line and Primo. These products repurpose former food items discarded by the food industry, transforming them into high-value ingredients with reduced environmental footprints compared to traditional animal feed, while preserving high nutritional quality. The session will detail the development of an ISO 14040/14044-compliant LCA, aligned with GFLI methodology—rooted in FAO's LEAP guidelines for animal feed and the EU's feed PEFCR. Furthermore, it will discuss strategies for clear communication with investors and customers, paving the way for funding opportunities and seamless market adoption.

Circularity - not so straightforward: A review of methodological choices in LCA for circular renovations of buildings

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Background and Purpose: Today, buildings are responsible for roughly 40% of the 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 been developed for linear systems and, in the built environment (BE), for new construction developments. Therefore, the application of LCA to a CE context, particularly for renovation projects, warrants methodological caution.

Methods: This paper presents a systematic review following the PRISMA reporting guidelines, exploring the complexities and key considerations when evaluating circularity and environmental performance of renovation projects through LCA. Traditional LCA methods may not accurately represent the impacts associated with circularity, leading to distorted evaluations. Central to the investigation are questions regarding the treatment of the existing building, impact allocation approaches, the reference study period, dynamism and biogenic carbon accounting. Building on these theoretical foundations, this study conducts an exploratory LCA combined with a sensitivity analysis to investigate how methodological choices influence assessment outcomes and subsequent decision-making in renovation projects, aiming to identify which parameters

have a significant effect on the results and therefore warrant deeper investigation.

Results: Findings indicate a lack of consensus on methodological approaches such as whether or not to include the existing building in the scope of the analysis. The study demonstrates how different methodological choices can alter LCA results and in turn influence decision-making. Despite these variations, few studies critically reflect on the consequences of their choices.

Conclusion: Through both theoretical review and subsequent practical application, the research contributes to the ongoing debate on adapting LCA practices to align more effectively with the CE in the built environment, ultimately guiding better-informed decisions for sustainable and circular renovations.

Life Cycle Assessment of Hybrid Copper Smelting

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The demand for resources for facilities of power generation, transmission and distribution is increasing due to the shift to renewable energy recently. Above all, the demand for copper is expected to increase significantly. In addition, the grade of copper ore is declining year by year. Therefore, it is essential to promote copper recycling in order to meet demand. In this study, we calculated the life cycle environmental impact of copper smelting considering the blending ratio of recycled raw materials. In copper smelting, not only is the oxidation heat generated during processing copper concentrates and copper matte used as the main heat source, but excess heat is also used to process recycled raw materials, such as copper scrap. Therefore, in copper smelting, there is an upper limit on the blending ratio of recycled raw materials, and when the blending ratio increases, the additional heat source should be necessary due to the lack of heat. Therefore, the environmental impact when the blending ratio of recycled raw materials is increased from the current process might be higher than the current process. Although copper smelting is a mature technology, there is still potential to improve recycling rates at many existing smelters. In prior studies, the blending ratio of primary raw materials and recycled raw materials has not yet been considered for the calculation the life cycle environmental impact of copper smelting. Therefore, the purpose of this study is to derive the future optimal scenario of copper smelting when considering the blending ratio of primary raw materials and recycled raw materials.

Challenges in assessing potential long-term effects of metals releases from mine tailings in LCA

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Mine tailings are the gangue resulting from mineral processing activities that turn ores into saleable metals concentrates. Due to their nature (a mix of ground rocks, water, and chemicals), their management, storage or disposal may have environmental impacts that could occur over long periods. Only a few published life cycle assessment (LCA) studies focusing on mining or metal production include tailings management directly in product systems. In cases where mining is in the background of the product system, mine tailings can appear as environmental hotspots for toxicity and ecotoxicity impacts due to poor flow modelling choices.

This work reviews six models that have been used in LCA, comparing: i) the nature of the model; ii) parameters used to consider tailings composition, climatic conditions, geochemical processes and the design of the tailings storage facility; iii) usage of the models and; iv) timeframes considered in the models.

Differences along these dimensions result in orders-of-magnitude differences in calculated potential impacts when considering tailings associated with the mining of copper on a 100-year timeframe. In particu-

lar, the more realistic , the model, the smaller the predicted impact. During a workshop at the SETAC Europe 34th Annual Meeting in 2024, a group of metals ecotoxicologists and experienced LCA practitioners discussed these findings and the completeness, time horizon and operationality of different models. The group proposed that existing models projecting to 60.000 years are not reliable in a regulatory context, and new models could yield more realistic life cycle inventories (LCIs) for tailings impoundments. This improvement calls for an interdisciplinarity approach.

Data and modelling challenges along the supply chain for aluminium in Europe at the onset of the LCI Environmental Footprint 4.0 database

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The Environmental Footprint (EF) 4.0 LCI Database is a secondary database for life cycle inventory datasets currently under development by the European Commission. The goal of the EF 4.0 LCI Database is to allow users to perform EF-compliant LCA studies, according to the PEF Method and to the available Product Environmental Footprint Category Rules (PEFCR) and Organisation Environmental Footprint Category Rules (OEFCR).

The EF 4.0 Database comprises different core data packages, each specific to a different type of commodity and process. One of the cornerstones of the database is the core data package for Metals & Minerals. Aluminium is a strategic raw material for European industry and can be instrumental in achieving a low-carbon and circular economy in many industrial applications. As a result, ensuring the best representation of the value chain of aluminium for the European market has been a key target during the development of the EF 4.0 LCI Database.

Available LCI data from aluminium industry associations (EU Aluminium for Europe, IAI - International Aluminium Institute for other regions) was used to inform the list of datasets to be developed, and to model the life cycle inventory of aluminium datasets. The use of primary data collected by industry associations ensures higher transparency and consistency for LCA users and practitioners. EF 4.0 modelling requirements rely on modelling recycled content through CFF, water characterization factors based on AWARE, and a new impact category for land-use-induced impacts on biodiversity.

Availability of primary data for bauxite mining regions, and consistent modelling criteria for energy and recycling, are crucial for the aluminium metal industry to pursue sector sustainability strategies. The goal of this paper is to display challenges, data gaps and the effect of different modelling choices encountered during the modelling of bauxite and aluminium datasets for the EF 4.0 Database.

Life Cycle Assessment of an electronic pump: focus on mineral and metallic resources

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This paper aims to evaluate the environmental performance of an electronically controlled pump produced in Italy through a Life Cycle Assessment (LCA) study. The analysis covers all life cycle stages, from raw material extraction to production, use phase, and final disposal, including all related transport. The LCA is conducted according to the international standards ISO 14040 and ISO 14044, and the results are expressed in terms of eleven impact categories, using the CML-IA v4.8 2016 method, with a focus on one year of operation and ten years (service life). For the one-year scenario, the production and processing of raw materials dominate all categories, while for the entire life, the use phase (related to electricity consumption) has the highest contribution across all categories. The category with the highest contribution from raw material production is “Abiotic resource depletion – minerals and metals,” and therefore, the types of materials

responsible for this impact are further examined. Given the large number of components in the analyzed pump, the materials are grouped into metals, plastics, ceramics, composites, electronics, and others. The analysis reveals that electronic materials have the dominant impact, followed by metals. Despite their low weight in the total product, electronics contribute over 50% to the "Abiotic resource depletion – minerals and metals" category due to the presence of gold and silver, while copper is the primary contributor to the impact in the case of metals. Focusing on mineral and metal resources, an additional impact assessment is performed using methods other than CML-IA, based on different characterization models and their associated factors. This approach highlights the dominant resources through various methods, emphasizing potential similarities or differences in the results.

Building a High-Quality Database: The Critical Review Process

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The quality of datasets within life cycle inventory databases is critical to ensuring reliable LCA results. These datasets often contain inconsistencies or incomplete documentation, highlighting the importance of systematic reviews to uphold data integrity and transparency. This work focuses on a critical review methodology applied to the CicloData project—a national database of life cycle inventories developed for the Metropolitan Region of Chile—as a case study to address these challenges.

The methodology begins with the selection of reviewers through a scoring system that evaluates their expertise. The evaluation includes criteria such as experience in LCA reviews, involvement in related projects, and knowledge of technologies relevant to the dataset under review. This ensures that the reviewers hold the necessary qualifications to deliver objective and high-quality evaluations.

The critical review process follows a S.M.A.R.T. approach—Specific, Measurable, Achievable, Relevant, and Time-bound—designed to methodically assess each dataset component. Key aspects reviewed include nomenclature, mass and energy balances, and documentation, among others. A detailed plan prioritizes addressing identified issues based on their impact and urgency, ensuring a systematic and efficient workflow.

The results demonstrate that this methodology ensures life cycle datasets meet international standards, fostering consistency, transparency, and accuracy. Additionally, it establishes a framework for continuous improvement by periodically identifying and addressing dataset inconsistencies. This iterative process not only enhances the applicability of datasets in future LCAs but also creates a foundation for collaboration among experts and transparency for end users.

In conclusion, the development and implementation of systematic, future-proof critical review processes are essential to support reliable environmental assessments. By combining rigorous review methodologies with clear guidelines and expert collaboration, this approach addresses emerging challenges in critical review while ensuring the integrity of data used for sustainability decision-making.

Social Sustainability and Energy Communities

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Social sustainability, an essential component of the SDGs, is closely related to the environmental and economic dimensions. It seeks to strengthen all actors involved in production processes in terms of human development. Despite its relevance, the measurement of this dimension still presents major methodological challenges. This key component of sustainable production is little studied and the lack of a clear methodology for its measurement complicates both its evaluation and the collection of the corresponding

indicators.

The tool in development that facilitates this analysis is the Social Life Cycle Analysis (S-LCA), which offers a framework for evaluating the social impacts of a product or service throughout its life cycle. It is based on the methodology established by ISO 14040, incorporating social categories and indicators, evaluating a product or service throughout the five stages of its life cycle: obtaining resources, manufacturing, marketing, use and disposal.

This study proposes applying the S-LCA to evaluate a rural energy community, with the aim of identifying relevant indicators and assessing their contribution to social sustainability in specific contexts, demonstrating how this methodology can contribute to informed decision-making and the promotion of more equitable and sustainable projects. This will be carried out using the UNEP/SETAC methodology and selecting indicators adapted to the rural context of off-grid energy communities in Latin America.

Life Cycle Assessment of Nitrile Medical Examination Gloves: A Multi-Variant Study Across Central Medicare Sdn Bhd's Manufacturing Facilities

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This study presents a comprehensive life cycle assessment (LCA) of nitrile medical examination gloves manufactured by Central Medicare Sdn Bhd, a subsidiary of HARPS Global Group in the global glove industry. The assessment covers 11 product variants produced across four distinct manufacturing blocks (Block B, E, F and G), resulting in the generation of over 40 individual LCA profiles. Utilizing a cradle-to-grave approach aligned with ISO 14040/44 standards, the outcomes was independently reviewed by Bureau Veritas Sweden based on ISO14071 standard.

The findings reveal significant variability in environmental performance across glove types and production lines, driven by differences in material composition, process efficiencies, and operational practices. The comprehensive dataset provides valuable benchmarks and identifies potential hotspots for targeted environmental performance improvements. Moreover, this LCA serves as a foundational step toward enhancing sustainability in the production and application of nitrile gloves, especially in medical examination settings where demand and regulatory scrutiny are high.

By mapping detailed environmental impacts across a diverse product range, the study supports data-driven decision-making for future process optimization, continuous improvement & eco-design initiatives, and environmental certification such as Environmental Product Declaration. The outcomes also contribute to broader sustainability goals within the medical supply chain, reinforcing HARPS's commitment to responsible manufacturing practices.

Disposables and reusables in the hospital sector: The warm jackets project at Oslo University Hospital.

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The use of disposable plastic equipment in the healthcare sector has been a topic of concern, due to its large-scale use and the implications it has for both the environment and users' health. Staff at hospitals in Norway use synthetic, single-use warm jackets when they need an added layer of clothing inside the hospital. A potential replacement with reusable jackets could lead to a significant reduction in plastic use and waste, however it is important to avoid shifting environmental issues from one area to another. The goal of this project was to deliver the knowledge-base that decision-makers need about life cycle sustainability to make well-informed decisions about the procurement of warm jackets for health professionals. Sustaina-

bility LCA (LCSA) has been applied to compare the reusable and disposable systems. The results of both the environmental LCA (E-LCA) and social LCA (S-LCA) showed that the majority of the environmental impact categories and overall social risks had better results for the reusable alternative. The life cycle costing (LCC) analysis showed that the multiuse system had overall costs less than 80% of the total costs of the single-use. Sensitivity analysis showed that the E-LCA damage results for the multiuse are still no worse than those for the single-use if the number of uses is as low as 19. Laundry impacts are important for the overall impacts and damage associated with the multiuse system, however even if the least efficient laundry service is used, the multiuse system performs better for E-LCA endpoint damage. The LCC sensitivity analysis showed that the purchase price for a multiuse jacket would need to be 38.5 times the price for a single-use jacket for the total cost for the multiuse system to be as high as for the single-use system.

The project was supported by the Norwegian Retailers Environment Fund.

Reusing non-sterile medical items through different disinfection methods: a comparative Life Cycle Assessment with single-use alternatives in a Belgian hospital

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For reasons such as low purchase cost, ease of use, time savings, patient safety, disease outbreaks in the past, hospitals experienced a shift from reusable to single-use items. Rising consumption of single-use items is associated with an increase in waste. Awareness is, therefore, growing about the need for a circular healthcare sector. However, when introducing reusable non-sterile medical items, increased use of single-use disinfection wipes should be avoided to align with the circularity principle. A study conducted by the Ghent University Hospital in Belgium, and funded by Circular Flanders, aims to replace non-sterile single-use medical items by reusables in the patient care departments of the hospital and to investigate how these can be reused by testing automatic and manual disinfection methods. The environmental sustainability of the reusable medical items compared to their single-use alternatives is evaluated through a cradle-to-grave Life Cycle Assessment. An automatic washing disinfector is compared with two manual disinfection methods, i.e., single-use wet wipes or disinfection spray applied with a reusable cloth. Based on criteria such as used quantity in the hospital, pill cups and drinking cups for liquid medication intake are selected as first case studies. Life cycle inventory data are collected from October 2024 until March 2025. Primary data are collected from the Ghent University Hospital and its suppliers. The environmental impact assessment will be performed in the first half of 2025 and will include both midpoint results (e.g., global warming, water consumption, etc.) and endpoints results (e.g., damage to human health). The results of this study will enable the identification of environmental hotspots in the life cycle of reusable and single-use items as well as the disinfection methods, and can be used in decision-making about using (again) more reusable items in a hospital context.

LCA as an essential tool for process development: bio-based carbon fiber production - from research to industry

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Bio-based materials are expected to play a key role in the defossilization of the global economy. As many bio-based production routes are still in the early stages of development, it is important to ensure a positive contribution to environmental sustainability during process development. Life Cycle Assessment (LCA) can support this development by identifying potential negative impacts. However, conducting LCA at early stages of research is challenging, mainly due to limited data availability and differences in process maturity. These challenges can hinder comparisons between alternative and conventional processes, ultimately preventing the extraction of actionable guidance for further sustainable process development.

We address the challenge of lacking data and the need for actionable guidance during process development in an industrial research project. For this purpose, we integrate LCA at an early stage of this project and apply a prospective LCA to guide the upscaling development. We align LCA with process development through a structured workflow - based on the guidelines for early-stage chemical process assessments by Langhorst et al.[1] This workflow addresses critical issues during the development phase and enables environmental decision making early on.

The industrial project focuses on advancing bio-based carbon fiber production using bio-based acrylonitrile (AN) derived from glycerol, a biodiesel by-product. Initial assessments reveal promising environmental benefits: a 40% reduction in greenhouse gas emissions and a 31% reduction in water consumption compared to fossil-based processes. Following this industrial case-study, we showcase how the workflow by Langhorst et al. can be applied to bio-based processes to identify areas for improvement as the process evolves, enabling continuous and informed decision making. We highlight the value of tailored integration of LCA in the early stages of research and development and discuss potential pitfalls and limitations to support practitioners applying the tool for their case-studies.

[1] https://dx.doi.org/10.7302/4190.

Probabilistic Multi-perspective Application Selection for Safe and Sustainable-by-Design: A Case Study on Biochar

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Here, we propose the Probabilistic Multi-perspective Application Selection (pMPAS) to identify Safe and Sustaina-ble-by-Design (SSbD) applications for novel materials. Although not a novel material, biochar has been selected as the subject of this pMPAS case study because its growing prominence for CO2 removal (CDR) is also fostering novel applications. Novel biochar applications aim for extended carbon storage (particularly for low-quality bio-chars that degrade faster) by prolonging biochar's use phase, delaying its environmental release, and consequent degradation. Nevertheless, an SSbD assessment for novel biochar applications is necessary to understand and balance trade-offs between CDR and toxicity concerns (from heavy metals, polycyclic aromatic hydrocarbons, etc.). Therefore, this pMPAS case study stochastically scores the functionality, (human and environmental) safety, (environmental) sustainability, and economics of 15 novel biochars for an SSbD ranking wherein Animal Feed, Passive Cooling, and Concrete Aggregates rank the highest, whereas Reductants, Plastic Additives, and Carbon Nano-materials rank the lowest.

Applying Life Cycle Assessment to the Production of Sustainable Backfilling and Subfoundation Materials from Local Mineral Wastes in Wallonia, Belgium

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To ensure a sustainable future, the construction sector in Wallonia (Belgium) is embracing circular economy principles, aiming to reduce environmental impacts while fostering economic growth. Within this context, the WASTES2MAT project, under the REMIND portfolio (Reverse Mineral Industry in Wallonia), investigates the environmental and technical feasibility of using locally recycled mineral resources, such as dredging sediments, gypsum paper, and mineral sludges, as backfilling and subfoundation materials in construction applications.

The project focuses on transforming these secondary materials, which are currently classified as waste and often sent to landfills, into valuable construction resources. This involves overcoming challenges related to their low mechanical performance while minimizing environmental impacts and ensuring cost-competitiveness with conventional natural materials. The environmental assessment of these materials encompasses their entire life cycle, aiming to reduce natural resource consumption and divert waste from landfills.

Industrial partners conduct rigorous standardized testing to validate the technical performance of the developed materials, while the University of Liège applies life cycle thinking to evaluate their environmental benefits. A comprehensive Life Cycle Assessment (LCA), adhering to the EN15804+A2 standard, serves as the foundation for eco-design and decision-making. This LCA approach informs strategic alternative choices and supports the scalability of the materials for regional markets.

The study is expected to yield resource-efficient, low-impact construction materials, presenting new business opportunities and shaping Wallonia's economic future. It highlights the importance of integrating sustainability assessments in construction, demonstrating how circular economy principles can drive innovation, reduce dependency on natural resources, and create cost-effective alternatives. This approach sets a benchmark for future initiatives, combining environmental stewardship with economic and social benefits, ultimately contributing to a resilient, circular construction ecosystem.

Accelerated carbonation of Municipal Solid Waste Incineration Bottom Ash (MSWI-BA) for sustainable low-cement concrete: a Life Cycle Assessment approach

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Municipal solid waste incineration bottom ash (MSWI-BA) is a residual material generated during waste incineration. Usually, it is used as a substitute for sand and natural aggregates in road construction and concrete pavements after a maturation process involving atmospheric exposure for at least 18 weeks. This study investigates an accelerated carbonation process to expedite the maturation of MSWI-BA into low-cement concrete formulations. The project aligns with eco-conscious technological priorities, reducing environmental (including carbon) footprints and promoting circularity.

Eco-design strategies, guided by Life Cycle Assessment (LCA) from the early stages of development, support the optimization of low-cement concrete incorporating MSWI-BA. This approach evaluates carbon capture and storage potentials during carbonation and informs roadmaps for recyclability and resource efficiency. The study quantifies the environmental impacts of producing an innovative concrete block with a 30-year lifespan and a compressive strength of 40 MPa. Following the EN 15804 + A2 norm, the LCA employs a cradle-to-gate scope modelled in SimaPro 9.6.0.1. The inventory was based on primary data

collected from project partners and Ecoinvent 3.10 database was used as a secondary data source.

The objective includes assessing impacts of producing carbonated concrete blocks, evaluating alternative formulations by substituting raw materials with by-products and reducing hydraulic binder content, identifying impactful life cycle stages and processes, and comparing the product's environmental performance with traditional road infrastructure materials.

Results demonstrate a significant reduction in the environmental footprint of low-cement concrete compared to conventional Portland cement-based concrete, attributed to applied eco-design strategies.

This study highlights the potential of integrating MSWI-BA with accelerated carbonation as a sustainable solution for advancing low-impact construction materials.

Refinements to Land Use Change (LUC) assessments and its augmentation by use of Satellite imagery data for a case study on bio-based feedstocks for plastics .

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The quest for carbon neutrality has taken on a fast-track in recent years. This is expected to accelerate progress on decarbonization of products across different solution directions. One such key solution direction is the production of petrochemical products such as plastics and chemicals based on bio-based feedstocks.

LCA studies of bio feedstock-based plastics and chemicals has an important linkage to land use change impacts. Conventional LCA studies focus on Direct Land use change and shows high dependencies linked to primary data on land-use change impacts. The LUC impacts computation framework is also based on the use of average regional and national statistics on LUC. This work evaluates refinement to LUC assessments using implementation of first principles driven equation that incorporates specific tools and approaches each of the various components of LUC impacts such as above and below-ground biomass based carbon stock changes, forest edge effects, etc. The study also highlights the valuable role which inventory data such as satellite images and LCA inventory analysis techniques based on statistical analysis can play towards improved representation of LUC impacts. This also helps to infer on the broader significance related to supplier-specific LUC impacts. The study will also analyze the sensitivity of impacts to refinements in resolution and representativeness of data. The approach has been validated with a case study based on Palm oil-based bio-sourced feedstock for petrochemicals production leading to refinements to LUC estimates of around 30%. The work will also aim to describe the potential role that machine learning could play towards augmenting the quality of data used in LCA studies on LUC emissions for bio feedstock sourced plastics.

From Waste to Value: Comparative Life Cycle Assessment of Recycled Plastics in a Circular Economy

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The search for solutions that align productive efficiency with sustainability is essential in the plastics industry, especially in the face of growing demands for circular economy practices. In this context, comparing the environmental impacts of virgin and recycled plastic resins presents a relevant strategy for fostering environmentally sound decisions and innovation in industrial processes. This study presents a comparative Life Cycle Assessment (LCA) between virgin PP resin and PCR PP resin from the "Balde vira Balde" project, a recycled material derived from construction and demolition waste, developed to offer higher quality and

sustainability. The analysis adopts a "cradle-to-gate" approach, considering raw material extraction through to industrial production. The methodology follows ISO 14040 and 14044 standards, combined with the European Union's Product Environmental Footprint (PEF) approach. Atmospheric emissions, effluent generation, and solid waste are analyzed throughout the production cycle. The collected data will be modeled using GaBi Professional software, and the results will be assessed across the 16 impact categories defined by PEF. It is expected that the recycled resins will perform better environmentally compared to virgin resin, with lower greenhouse gas emissions and greater efficiency in natural resource usage. Studies like this not only highlight the environmental benefits of recycled materials but also help the market adopt more sustainable practices, promoting competitiveness, regulatory alignment, and stakeholder engagement. Thus, the analysis contributes to solidifying the role of the plastics industry in the transition to a circular and resilient economy.

Substituting Fossil-Derived Plastics with Biomass-and-Waste-Derived Alternatives for Carbon Reduction: A Flow Analysis of Japan

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Biomass-and-waste-derived plastics are being promoted as renewable carbon-based materials to replace fossil-derived plastics. However, the environmental benefits of these materials are not guaranteed because the environmental impacts of processes such as biomass supply remain uncertain. In addition, a lack of organized knowledge about the life cycle of plastics, especially on new adopted resins and new manufacturing technologies, has made it challenging for the stakeholders to design a plastic with comprehensive assessment. From the perspective of sustainable development, it is important to examine the effects of renewable carbon-based plastics and discuss the best pathway and combinations for introducing the resources and technologies.

This study aims to clarify the life cycle of biomass-and-recycled-derived plastics through flow analysis and assess the renewability of carbon sources and their environmental impacts. We also explore appropriate ways to introduce biomass and waste as carbon sources.

In the flow analysis, greenhouse gas emissions were chosen as the key indicator. For renewability, factors such as the amount of crude oil used as a raw material and the share of renewable carbon in the system were assessed. Technical information about plastics was collected through bibliometric analysis, and the system boundaries for flow analysis were defined based on the current situation in Japan. Inventory data and unit values for each process required for the analysis were based on existing research and literature, with process simulations filling in any gaps.

The results of the flow analysis showed how introducing biomass and waste into the system affects environmental impacts and the renewability of resources. Additionally, the study identified key raw materials and recycling technologies, as well as their combinations, that should be prioritized to maximize the advantages of biomass-and-waste-derived plastics. For example, it became clear that fossil-derived PS should be replaced as a priority by biomass-derived plastics or by recycled resins.

Circular Economy in Furniture: Assessing the Environmental Performance of Waste Based Boards

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Historically, furniture was designed to last a lifetime, but modern furniture is cheaper and less durable, leading to more waste. This study aims to develop and evaluate sustainable boards for modern furniture made from up to 90% waste materials, comparing their environmental impact

to traditional materials.

Several formulations were considered for board production, using virgin polymers and waste materials such as bottle label waste (work waste) and Acrylonitrile Butadiene Styrene (ABS) with sawdust as waste from the proper furniture industry. The sustainable boards were developed at a laboratory scale and characterised mechanically, environmentally, and economically. The Life Cycle Assessment and Life Cycle Cost (LCC) analysis followed ISO 14040:14044 standards. The ReCiPe Midpoint Hierarchist perspective method was used. The LCC included internal and external costs, with external costs calculated using CE Delft's 2023 conversion factors. Mechanical characterisation evaluated density, flexural strength, and modulus of elasticity. The study follows a "cradle to gate" approach, defining the declared unit as 1 m^3 of board production. A decision-making matrix was used to score each criterion, identifying the most promising formulations for industrial-scale testing. Four formulations were selected for industrial-scale production: i) 80% work waste + 20% Polyurethane, ii) 100% work waste, iii) 80% work waste + 20% Polyethylene, and iv) 80% work waste + 20% ABS and sawdust. Mechanically, the best-performing formulation was iv). Environmentally and economically, the best formulations were ii) and iv), mainly due to the high content of waste materials. Industrial-scale trials showed that formulation iv), followed by ii), excelled in environmental, economic, and mechanical performance. They offer the best alternatives to traditional materials, supporting a circular economy while maintaining high functionality.

This research was supported by the NextGenerationEU program as Recovery and Resilience Facility Plan applied in Portugal, with the code number RE-CO5-i01.02 Sustainable Plastics, WP1 PPS2 Eco board.

From Waste-to-Resource: How Collection Methods and Sorting Performance shape Plastic Waste Management Impacts

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Global annual production of plastic waste is projected to increase from 389 Mt in 2023 to 687 Mt by 2050. This increase poses significant challenges to plastic waste management and underlines the importance of plastic circularity to decrease virgin resource demand and greenhouse gas emissions. Achieving high quality recycled plastic feedstocks requires high-precision sorting of household waste as properties of plastic differ. However, currently there is a large variation in rejected collected waste due to inconsistent purity of the plastic waste streams. There exist multiple collection methods, such as pre-sorting (also called source separation) and post-sorting, but their effect on both the quality of recycled plastic feedstock and associated (avoided) environmental impact are understudied. Here, we investigate the influence of collection method on the recyclability of sorted plastic waste streams and determine the (avoided) environmental impact based on downstream treatment of the waste streams. This study compares two plastic waste collection methods, pre-sorting and post-sorting, from "waste" to recycled plastic feedstock ("resource"). Different rejection and contamination rates are associated with each collection method and their resulting downstream treatment per waste stream is mapped, leading to different recycling efficiencies. Additionally,

The differences between cities in sorting performance is analysed to assess its impact on achieving policy targets for recycling and identify the potential of behavioural interventions. For each collection method, the effect and its associated (avoided) carbon footprint of their downstream treatment pathways are calculated using life cycle assessment (LCA). The results of this study can be used to compare greenhouse gas reduction benefits and recycling efficiencies of alternative collection methods. These outcomes can identify improvement opportunities for plastic waste management to ensure high quality recycled plastic feedstocks, increase recycling rates, and reduce the carbon footprint related to plastic production.

Separate or curbside collection? Identifying the path to high-quality plastics recycling with LCA

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The Austrian state of Upper Austria (UA) heavily relies on private waste separation in households, which is curious as curbside collection has been a trend in western societies over decades. In UA residents collect their waste at home and drive to collection centres where employees guide them on how to properly separate their waste. Plastic waste is also collected there and a higher degree of separation is achieved. As recent LCA research points out - to achieve the highest possible emission savings and to increase the overall recycling quota high-quality recycling products are needed. In the past many studies assumed 1:1 substitutability without proving those claims by transforming the obtained recyclates into applications.

Therefore, in the work at hand, those thoroughly separated film fractions are converted by a novel pilot-sized process design into various products and LCA is performed in an accompanying way. Moreover, the results will be benchmarked against the more classic case of the 'yellow bag', which will be modelled on an excellent primary data collection effort, as not only the biggest recycling company in the state but also several waste management authorities are part of the project. As the work focusses on every day products, realistic routes are drawn, as exact transportation pathways as well as the relevant means of transport are known to the LCA team. Therefore, the up-and downsides of private collection versus curbside collection can be assessed via LCA allowing for robust results which facilitate policy recommendations.

To extend the work's relevance, those routes, both focussing on post-consumer material, will be benchmarked against another case, in which post-industrial material is recycled at an existing recycling plant. Therefore, LCA can guide the way forward in high-quality plastic film recycling.

Reducing marine litter and microplastics from fishing industry – a case example from SEARCULAR project

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Plastic pollution in oceans is a well-known problem. It is estimated that nearly 10% of the marine litter originates from the fishing industry. The EU Horizon project SEARCULAR aims to find ways to reduce marine litter and microplastics from fishery through four case studies: dolly ropes from recycled fishing gears, biobased seine ropes, biobased drifting Fish Aggregating Devices (dFADS) and collection systems at ports for end-of-life treatment of fishing gears.

This study focuses on assessing the environmental impacts and sustainability of dolly ropes made from recycled PA. The environmental impact of traditional dolly ropes made from polyethylene are compared with dolly ropes made from recycled polyamide. Recycled polyamide is expected to be more durable against abrasion than the traditional polyethylene and can thus reduce the release of plastics and micro-

plastics to the oceans. The mechanically recycled polyamide is produced from collected purse seine nets at the end of their life, i.e. from the fishing industry, thus also reducing marine litter. The assessment will cover the production stage of both dolly rope alternatives and their performance in real fishing operation conditions onboard.

The environmental impact of the recycled polyamide-based dolly ropes will be studied with life cycle assessment (LCA) method (ISO 14040-44) and compared to the traditional alternative with similar functionalities. The environmental impacts will be studied with the Environmental Footprint 3.1 (EF3.1) impact assessment method suggested by the European Commission. In addition, potential impacts of microplastics emissions will be assessed with two new available impact methodologies to understand the importance of microplastic emissions in the total environmental footprint context and to compare the differences between the different microplastics assessment methodologies.

Sustainability Assessment in the Buddie-pack project

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Over 140 million tonnes of plastic packaging is produced annually worldwide, the majority of which currently goes to waste. The EU Horizon funded Buddie-pack project aims to develop and demonstrate sustainable strategies for reusable plastic packaging. Strands of work on packaging design, behaviour change and sustainability assessment are combined in 5 large case demonstrations. This presentation will present findings, successes and challenges from the comprehensive sustainability assessment.

Environmental and Economic Life Cycle Assessment is concurrently informed by and informs the development of large-scale demonstrations. Preliminary assessment found that break-even points are heavily impacted by the mass and material of the reusable packaging. In the case of a takeaway container, break-even points for global warming potential of 4 and 17 uses were calculated masses of 40g and 182g. These findings showed the importance of including environmental impact assessment in packaging design and performance optimisation, even in challenging cases, such as raw meat packaging.

Social Life Cycle Assessment was undertaken using the Social Hotspot Database (SHDB), providing data on 140 countries, 57 industrial sectors and 155 potential indicators. For a series of indicators, countries of interest for each lifecycle phase were identified through Harvard's 'Atlas of Economic Complexity'. Combining this data allowed the collation of a map of S-LCA indicator risk related to reusable plastic packaging.

A set of circularity indicators have been developed, combining the Product Circularity Indicator method, environmental, economic and social indicators, and additional impact indicators including total litter or packaging effect on food waste. The indicator combines these values to give designers a holistic measure in a range from A-G.

Results show the importance of considering a range of environmental, economic and social impacts. There is no "one size fits all" set of rules and each use case should be evaluated to determine the "most sustainable" option.

Environmental Ashby chart for various applications of cellulose nanofibers

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New materials often exhibit superior and unique properties and are typically associated with higher environmental impacts during production. Better performance during use—enabled by superior material properties—can offset the higher impacts during production. A typical example is the use of high-tensile strength steel as a superior material alternative to conventional mild steel for lightweighting vehicles to improve fuel efficiency during vehicle operation. Understanding the connections between material properties and environmental impacts is crucial for material selection and product design. However, there remains a lack of research quantifying the relationship. Therefore, the objective of this work is to develop an Environmental Ashby chart to quantify the relationship between material properties and environmental impacts. Cellulose nanofibers (CNFs) are used as an example. As an emerging class of sustainable materials derived from renewable resources, CNFs are promising candidates to substitute petroleum-based polymers due to their favorable mechanical properties. Under the current state of technological development, CNFs are usually used as additives in conventional plastics or composites, such as CNF-polypropylene (CNF-PP), CNF-polyethylene (CNF-PE), CNF-epoxy, and CNF-carbon-fiber reinforced polymers (CNF-CFRP), collectively referred to as CNF-enabled materials in this work. CNF-enabled materials with varying compositions of CNFs exhibit different mechanical properties, such as tensile strength. The environmental impacts of CNF-enabled materials produced through specific processes were estimated using life cycle assessment. Finally, an Environmental Ashby chart was obtained to reflect the relationship between material properties and environmental impacts of CNF-enabled materials with varying CNF compositions. The application potential of these materials in various end-uses could vary depending on their properties. Considering the high environmental impacts during the production of new materials, this work contributes to optimizing the application of emerging materials with minimal environmental burdens.

Sustainability of different plastic packagings: Combined circularity and life cycle assessment for multiple R-strategies

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The transformation towards a Circular Economy (CE) aims to reduce negative environmental impacts, ensure supply security, and establish a sustainable and competitive economic system. At the micro level, this can be realized through innovative product systems that implement various R-strategies. To evaluate whether these systems genuinely support the transition to a sustainable CE, it is essential to assess their contribution towards achieving CE goals. While there are numerous indicators and methods in the literature for CE assessment, they predominantly focus on lower circularity R-strategies.

In this study, we investigate to which extent the packaging of a new detergent concentrate contributes to a sustainable CE compared to conventional bottled dishwashing detergent. We combine circularity assessment (CE indicators) with Life Cycle Assessment (LCA) within a comparative case study on two different packaging types for detergent: a plastic stand-up pouch for detergent concentrate versus a plastic bottle for conventional detergent. The case study covers multiple R-strategies but focuses on the packaging and its recyclability since the contained products are identical except for the life cycle stage where water is added.

We identify and apply relevant CE indicators based on literature review for both higher and lower R-strategies. Additionally, LCA is utilized to assess if high R-strategies offer environmental benefits compared to lower ones across various usage scenarios. A key difference between the two product systems lies in analyzing their behavior during sorting and recycling in the End-of-Life phase of the packaging after single

or multiple usage cycles.

The results primarily indicate whether the new detergent concentrate product system (covering multiple high R-strategies) is more circular and environmentally beneficial than conventional products regarding their packaging. This work also highlights the importance of combining circularity assessment with LCA and necessary indicators for constructive assessments of product systems as a discussion basis for future studies.

Quantifying the Performance of Circular Economy Strategies for E-Motors: Reuse, Repair, and Recycling

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The transition to a circular economy (CE) is critical for reducing resource consumption and mitigating environmental impacts, particularly in resource-intensive sectors such as electric vehicles (EVs). However, the shift to CE poses significant challenges in recirculating material flows in a manner that can promote eco-effectiveness. With the rising demand for EVs and sustainable transportation, automotive manufacturers face increasing pressure to adopt CE practices for EVs, specifically concerning permanent magnet (PM) motors, which are highly material-intensive and reliant on critical raw materials. This paper evaluates the performance of more circular complex product supply chains by applying Product Circularity Indictor (PCI) in a case study for PM motors. The case study results confirm that the improvement strategies based on CE thinking improve the circularity of the e-motor. Substituting concrete with more recyclable material positively impacts circularity performance, achieving a PCI of 0.296. The circularity improvement with increased collection rate is limited due to the overall low recovery rates for the e-motor. The study concludes with practical recommendations for policymakers, industry stakeholders, and researchers to foster circularity in the e-motor supply chain. By advancing CE strategies, this work contributes to the sustainable transition of the electric mobility sector and the development of resilient, resource-efficient systems.

Life Cycle Assessment of E-Methanol Production from Dates

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Saudi Arabia, the world's second-largest producer of dates, generates substantial agricultural residues, including fronds, pits, and low-quality dates. These underutilized resources present a promising opportunity to decarbonize the transport sector through sustainable e-fuel production. Building on our previous study, which demonstrated the technical feasibility of producing 1,430.78 kg/day of e-methanol by integrating ethanol fermentation (40% efficiency) and gasification of 1,153.28 kg/day of date biomass, this work advances the analysis by applying Life Cycle Management (LCM) principles. The previous process captured 362.7 kg/day of CO2 from fermentation and 1,099.22 kg/day from gasification, both of which were fully recycled into methanol synthesis.

In this study of a cradle-to-gate (well-to-tank) analysis , Life Cycle Inventory (LCI) data from GREET and Aspen Plus was used to quantify midpoint emissions, with a focus on climate change and photochemical ozone formation potential (POFP). Endpoint emissions were evaluated using a comparison of ReCiPe 2016 and GLAM methodologies, focusing on human health and ecosystem quality. In addition, Life Cycle Costing (LCC) and a Techno-Economic Analysis (TEA) were conducted to assess the economic feasibility and scalability of the process, further strengthening policy-making recommendations. Hotspot analysis identified hydrogen production via electrolysis, biomass transportation distances, and energy demands during

biomass preparation as critical contributors to environmental and economic impacts, providing actionable areas for optimization.

By integrating environmental and economic assessments, this study underscores the potential of circular carbon strategies, such as CO2 reuse and waste utilization, to reduce greenhouse gas emissions and resource consumption while maintaining cost-effectiveness. Policy recommendations include supporting renewable hydrogen infrastructure, promoting localized biomass utilization, and incentivizing carbon reuse technologies (carbon credits) to enable widespread adoption. This research highlights the importance of combining LCM, LCA, LCC, and TEA to inform sustainable fuel production and guide stakeholders in achieving Saudi Arabia's Vision 2030 and global 1.5°C climate targets.

Prospective LCA for Automotive Materials based on Interviews with the Japanese Materials Industries

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In order to work toward a sustainable society, it is important to conduct more sophisticated environmental impact assessments and consider specific future scenarios. Premise, a tool for prospective LCA, can create a future inventory database and conduct impact assessment by integrating scenarios generated by an integrated assessment model (IAM). On the other hand, prospective LCA using Premise may differ from the actual future vision presented by companies, etc., and the accuracy of geographical information may be low due to the Ecoinvent database used.

In this study, we devised and evaluated scenarios for the years 2020, 2030, 2040, and 2050, with a particular focus on automotive materials for automobiles. In addition to the use of Premise, these scenarios are characterized by the fact that they are based on the efforts toward carbon neutrality shown by the industries that manufacture steel, aluminum, and copper, which are used in Japanese automobiles. By performing a prospective LCA using this scenario, it is possible to show in detail the carbon neutrality initiatives that the Japanese automobile industry should promote in the future. In addition, in order to achieve a more sophisticated assessment, particularly with regard to the material recycling phase, we conducted an assessment using the Circular Footprint Formula (CFF) recommended by the European Commission. In this process, data based on interviews with the materials industry were used for each parameter included in the CFF.

Advancing recycling pathway decision-making for critical raw materials

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The increasing scarcity of critical raw materials (CRMs) necessitates innovative recycling strategies to support circular economy objectives. This study introduces a novel decision-support tool designed to optimize recycling pathways for CRM-containing products.

The tool employs material flow analysis, life-cycle assessment, and multi-objective optimization to derive the optimal recycling technology sequence for a given material, balancing material recovery efficiency, costs and environmental impact.

Material flow analysis is conducted using transfer coefficients that model the behavior of materials through various recycling processes based on material characteristics. Recycling process information is obtained through a thorough literature review and expert judgment. Environmental impacts are evaluated based on life-cycle inventories for each recycling technology, providing a comprehensive assessment of emissions, energy consumption and use of chemicals. Multi-objective optimization identifies trade-offs between com-

peting objectives, with results visualized through a Pareto front. This enables decision-makers to select recycling sequences aligned with specific priorities, such as minimizing environmental impact or maximizing cost efficiency.

The tool's scalability and adaptability are demonstrated through a case study on printed circuit boards, which play a crucial role in energy technologies and systems, showcasing its ability to deliver actionable insights for optimizing recycling systems.

Life Cycle Assessment and Levelized Cost of Storage of Secondary- and Primary-use LFP Batteries for Energy Storage Systems

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The transition to renewable energy sources such as solar and wind is critical for global decarbonization. However, the intermittency of these resources poses challenges for grid stability, necessitating the development of robust energy storage systems (ESS). Lithium-ion batteries (LIBs), particularly lithium iron phosphate (LFP) batteries, have emerged as a promising solution due to their long cycle life, cost-effectiveness, and safety. As the electric vehicle (EV) market continues to expand, a significant influx of retired LFP batteries is anticipated, creating opportunities to repurpose these batteries for stationary ESS applications. Secondary-use LFP batteries, retaining approximately 80% of their original capacity, offer the potential to reduce environmental impacts, align with circular economy principles, and decrease reliance on raw material extraction.

Existing studies suggest that secondary-use LFP batteries demonstrate superior environmental performance by avoiding raw material extraction. However, challenges such as higher repurposing costs and potential efficiency losses impact their economic viability. This research aims to address these challenges by quantifying the environmental and economic costs of electricity storage using LFP batteries from an exergy perspective, employing exergy as the functional unit.

By leveraging Life Cycle Assessment (LCA) and Levelized Cost of Storage (LCOS) frameworks, this study will provide a comparative analysis of the carbon and water impact categories, as well as the cost-effectiveness of secondary- and primary-use LFP batteries. Furthermore, uncertainty and sensitivity analyses will be conducted to identify key parameters influencing environmental and economic outcomes. These findings aim to enhance the robustness of sustainability assessments and provide actionable insights for optimizing energy storage systems while minimizing costs and environmental impacts.

Eco-design and LCA of emerging European photovoltaic technologies

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In recent years, solar energy has become essential not only to reach the decarbonization targets set in Europe by the Green Deal but also for the REPowerEU plan.

Europe was a front runner in the manufacturing of solar panels at the beginning of this century. However, in recent years Europe's solar industry has been facing an existential threat due to unfair competition with Chinese solar panels, offered below manufacturing costs. At the moment, 90% of solar panels installed in Europe come from China. Hence, at this critical moment for the European solar industry, it is essential to analyse the benefits of producing this technology in Europe as well as including the latest technical developments achieved.

To address this challenge, a life cycle assessment (LCA) is performed on the European patent technology silicon heterojunction–interdigitated back contact (SHJ-IBC). The main environmental hotspots are analy-

sed and compared with other technologies already in the market. Furthermore, a comparative study is performed between production in Europe and China.

Eco-design and cradle-to-grave assessments are performed in accordance with ISO 14040-44 standards. EF 3.1 is used as the impact assessment method. Primary data is collected by industrial partners and research centres. Background data comes from Ecoinvent 3.10 database .

Main outcomes are the reduction of the environmental impact of the SHJ-IBC modules by new technological improvements such as using thinner wafers, reducing silver content or higher efficiencies, among other parameters. In addition, manufacturing location also plays a key role in the environmental footprint, due to the electricity mix used at each production stage. Considering, the origin of photovoltaic modules is crucial to focus not only on the use phase but also the manufacturing and end-of-life stages.

This study shows the opportunities of novel European photovoltaic technologies and how their development could ensure a more sustainable energy transition.

Sustainability assessment of biogas and ethanol production pathways from winemaking residues: a comparative LCA study

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The transition towards sustainable energy solutions is critical for addressing global environmental challenges. Among renewable energy sources, biogas and ethanol have emerged as viable alternatives to fossil fuels. This study focuses on a comparative Life Cycle Assessment (LCA) of two valorization pathways for winemaking residues: biogas production from wine lees and grape pomace, and ethanol production in distilleries.

The environmental performance of these processes, considering typical key indicators such as greenhouse gas (GHG) emissions, energy efficiency, and resource utilization will be accessed. By comparing these pathways, the study aims to identify the option with the lower impact for managing winemaking residues, which are often underutilized or discarded, despite their potential to contribute to circular economy principles and decarbonization strategies.

Preliminary results suggest that biogas production may offer lower GHG emissions, while ethanol production has potential benefits in industrial integration and market value. However, the environmental impact of each pathway is influenced by regional factors, process optimization, and residue composition.

The findings of this study are expected to contribute to the broader discussion on sustainable waste management in the wine industry, providing insights into the potential for reducing environmental footprints and promoting renewable energy production.

Comprehensive Life Cycle Sustainability Assessment of Lithium-Ion Batteries for Electric Vehicles: Integrating Environmental, Economic, and Social Dimensions

Gaia Gentilucci, Antonella Accardo, Ezio Spessa

Politecnico di Torino, Italy

The transition to electric mobility relies heavily on battery technologies, but their sustainability raises critical questions. This study delves into the full life cycle of an automotive battery pack, with an NMC 811 chemistry and a capacity of 75 kWh, assessing its implications from environmental, economic, and social perspectives. The analysis adopts a holistic approach, combining Life Cycle Assessment (LCA), life cycle costing, and social life cycle assessment. The upstream supply chain includes the extraction and refining of critical raw materials in non-European regions, while battery production, use, and End-of-Life (EoL) stages are modeled within European countries. Three alternative scenarios are examined for the use and EoL to capture possible variations in outcomes. The results are expressed per functional unit, defined as the kilowatt-hour (kWh) of battery capacity. The LCA reveals that the carbon footprint ranges between 77.2 and 80.7 kg CO_2-equivalent/kWh. In terms of costs, the results fluctuate between 77.7 and 79.4 EUR/kWh. Social risk analysis exposes significant concerns regarding fair wages during raw material extraction, especially for cobalt (Democratic Republic of the Congo), manganese (South Africa), nickel and lithium (Australia), and graphite (China). Moreover, the assessment identifies substantial health and safety risks associated with the mining of cobalt, manganese, and nickel. Conversely, no major social challenges are detected in the use and EoL stages.

User-studies on Visualisation and Reporting of Life Cycle Sustainability Performance of Products

Olubukola Olumuyiwa Tokede[1], Anastasia Globa[2], Winter Jesse[3]

[1]Deakin University; [2]University of Sydney; [3]Institute of Social Neuroscience

Visualisation of Life Cycle Sustainability Assessment (LCSA) results is crucial in communicating sustainability preferences to various stakeholders and policymakers. Extended Realities, such as Augmented Reality (AR) and Extended Reality (XR) offers a more intuitive means to interpret the life cycle sustainability performance of products and projects, and constitute an invaluable approach to engaging users with no prior scientific knowledge. User-studies are vital in appraising and assessing technological interventions to improve usability, engagement and functionality of novel tools. Currently, there have been limited user-studies that have been deployed in developing the vast array of tools used in life cycle sustainability reporting.

This paper undertakes a comprehensive user-studies of the LCSA tracker – a novel XR tool used in visualising life cycle sustainability outcomes. The user-studies comprises of questionnaire surveys and co-design workshop of different user-groups (students, Industry professionals and Academics). It was found that the LCSA tracker performs well in usability, engagement and interactiveness. However, the user-studies identified opportunities for development with regards to data format, compatibility with existing platforms and data availability. Future work will seek to enhance user-experience by addressing the issues identified through the user-studies and will seek to build a community of practice for the LCSA tracker.

Session 1.13: Digital LCA/PCF data sharing for Collaboration & Innovation

Time: Wednesday, 10/Sept/2025: 2:40pm - 4:10pm
Session Chair: Lavanya Pawar, Carboledger, India
Session Chair: Purvish Shah, Carboledger, Inc., United States of America

CO2 Traceability: Enabling Data Sharing and Value Creation in the Value Chain

Elias Hallack, Lisa Rasmusson, Mats Berglund, Annica Iseback

AB SKF, Sweden

Driven by increasing customer demands and evolving legislation (e.g., the European Green Deal), companies are under growing pressure to provide product sustainability data on a large scale. This makes efficient data collection and sharing across the value chain a necessity.

SKF has initiated a project focused on achieving CO2 traceability throughout the full value chain leveraging available data, tools, and best practices. This presentation will outline the approach to CO2 traceability, share key learnings, and discuss the challenges and future work areas.

In the project, a traceability concept was implemented to track CO2 flows throughout the value chain. Traceability fosters collaboration among stakeholders and enables efficient data sharing and value creation. The applicability of ISO 14067 for developing a methodology to calculate large-scale PCFs was investigated.

We found that CO2 traceability enables collaboration and value creation along the value chain. Establishing product-level traceability enhances data sharing, transparency, and distributes the burden of data collection. In addition, traceability enables leveraging the collected data to engage with customers and identify new growth opportunities.

To effectively implement this approach, a review of companies' non-financial data collection requirements is crucial to identify gaps and align with the emerging demand for large-scale PCF data.

We identified key challenges including the absence of standardized data formats, data quality issues, and varying levels of sustainability maturity among value chain partners.

In conclusion, applying a traceability approach facilitates CO2 data sharing and enhances transparency. This approach can be extended to other types of sustainability data. Companies must invest in building sustainability skills and knowledge within their organizations, address data quality issues, and collaborate to develop industry-wide standards and guidelines.

An IT-Architecture for LCA, PCF and EPD supplier data collection, modelling and calculation

Friedrich Andreas Halstenberg, Andreas Ciroth, Ashrakat Hamed

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Motivation for the developed IT-Architecture were several industry projects for companies that needed to integrate LCA, PCF and EPD data from their suppliers. Additionally, they needed to integrate further data sources such as published EPDs from libraries of program operators and EC3. Since only a certain fraction of the respective suppliers was able to deliver the desired data, a combination of those data with conventional LCA background databases in a full LCA modelling and calculation approach was necessary.

Hence, we present a new IT-landscape that is tailored to support companies in efficiently collecting LCA, PCF and EPD data from suppliers. Through a customized web-tool, companies (such as OEMs) can request LCA, PCF and EPD data from their supplier network. Suppliers can deliver the requested data digitally in the web-tool, alongside with important meta data, such as applied PCRs and rule books, validities and data quality aspects such as external validation. The delivered data can be managed by the requesting company, checked for plausibility and imported into the open source LCA software openLCA. Here, the respective data are converted into LCA database elements such as results, EPDs and processes in a central, company-wide database on the openLCA collaboration server. A further way of integrating external data, is through published EPDs. They can be imported automatically from the EC3 platform or from further databases via the ILCD+EPD format. LCA practitioners can then use the delivered data and combine them with a wide array of background databases in their LCA models. The software supports all LCIA methods and offers various export formats and connected to further data repositories such as Catena-X and Together or Sustainability. Simplified tools for mass LCA calculation that can be used for non-LCA practitioners can be customized with onlineLCA based on the developed LCA models.

Unlocking synergies between PCF and EPD-Reporting - industry's path to a sustainable future or mere fantasy?

Florian Ansgar Jaeger[1], Benjamin Canaguier[2], Johannes Wunderlich[1], Manel Sansa[2], Matt Seiler[2]

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Product related LCA splits into two branches: LCA in design and LCA for procurement.

LCA in design has matured over the last decades and became a standard procedure for many companies to assess environmental impacts of their products. So far, the methodological focus has been on creating incentives to improve product designs. EPDs allow to report the result of this process in diverse impact categories.

LCA in procurement quickly evolves as Scope 3 targets confront companies with having to request PCFs (Product Carbon Footprints) from suppliers at a large scale. Companies heavily invest in PCF programs such as PACT, Catena-X, TfS, … . Opposed to product design focused LCAs, procurement driven PCFs rely on supply chain specificity for suppliers to distinguish themselves from competition. This is reflected in the methodological focus of PCF programs, e.g. reducing the use of secondary data or forcing market-based electricity modelling (e.g. Catena-X, TfS).

Companies now scaling up their reporting in EPD- and PCF-Programs face two main challenges. To reduce efforts and customer confusion, they strive to use the same calculation setup for both reporting streams by reporting results from EPDs as PCFs and using supplier PCFs to improve their EPDs.

Main obstacles in reporting PCFs as extracts from EPDs lay on the methodological side, as well as in their form of documentation. Using supplier PCFs of components or materials in LCAs for EPD declarations is additionally hindered by the fact that PCFs only provide few impact categories. Procedures for amending

the missing impact categories haven't reached acceptance in the LCA community yet.

This presentation provides an overview of the challenges and approaches to overcome the gaps between EPDs and PCF.

Enabling PCF Calculation in Supply Chains at Scale

Martina Prox

iPoint-Systems gmbh, Germany

Commitments to NetZero road maps and decarbonization pathways have drawn the attention to Scope 3 GHG emissions with several industry and cross-initiatives to harmonize Product Carbon Footprint (PCF) exchange formats, PCF calculation standards like WBCSD PACT, Together for Sustainability (TFS) or Catena-X. All initiatives focus on collecting product-specific, also referred to as primary data from suppliers, to enable reporting and monitoring of decarbonization progress of supply chains. After several years of developing, harmonizing technology and methodology standards, interoperable ecosystems for PCF data exchange across the supply chain are ready to role out and scale. In automotive industry also the International Material Data System (IMDS) in its next release is providing the possibility to share PCF data. What is seen as the remaining challenge to scale PCF data collection from suppliers, is making PCF calculation also for those suppliers accessible, which have little expertise and experience in calculating product carbon footprints, while at the same time ensuring that the use of production specific input data for PCF calculations is maximized. PCF calculation tools are observed to be either too complex, and suitable for expert users only, or oversimplified with the potential to lead to misleading or intransparent results.

The presentation will provide insights into concepts and solutions which address theses challenges to enable verifiable PCF calculations at scale. The approach presented enables each supplier to self-contextualize a PCF calculation solution using own bills of material, relevant mandatory production parameters and additional self-introduced production parameter. When providing PCF data to their customers for suppliers is becoming a must-have, PCF calculation needs to become accessible for the production engineering teams at the supplier, without going through comprehensive LCA and PCF trainings. It's iPoint's ambition to make this happen and the LCM audience should provide feedback the status of the approach and related solution.

Streamlining EPD Data Exchange: A Collaborative approach between manufacturer and general contractor for enhanced LCA comparison and transparency

Bertrand Touzet[1], William Lepercq[2], Antonin Falluel Morel[1], Gabriel Miche De Malleray[2]

[1]Eiffage, France; [2]Schneider Electric, France

The growing demand for transparent and comparable product carbon footprint (PCF) and life cycle assessment (LCA) data necessitates efficient digital solutions for data exchange across the value chain. This is particularly critical in the construction sector, where general contractors require reliable supplier data to make informed decisions and meet increasing customer demands for sustainable building practices. This presentation introduces a collaborative approach between Eiffage, a leading construction company, and Schneider Electric, a global specialist in energy management and automation, focused on streamlining EPD data exchange and enhancing LCA comparison practices within the construction industry.

We are jointly tackling the challenge of EPD comparability by identifying and cataloging key variations that influence comparability. This includes documenting differences in PCRs, declared unit, system boundaries,

data quality indicators, and life cycle stages considered.

By systematically addressing these variables, we aim to establish clear criteria for valid product comparisons based on EPD data and address inconsistencies that hinder effective decision-making.

Furthermore, we are working on designing a digital platform that automates the assessment of EPD comparability and facilitates data sharing between manufacturers and contractors. This platform will digitize key EPD information, enabling rapid and robust comparisons, ultimately supporting more informed product selection and promoting sustainable procurement.

This collaboration demonstrates best practices for PCF/LCA data exchange, aligning with emerging standards, while building upon existing frameworks like ISO 14040/44/67/25 and EPDs (FDES, PEP, EPD, PCF). By bridging the gap between manufacturers and general contractors, this innovative approach unlocks new business opportunities, empowers stakeholders for LCA and EPD transparent comparison and make data-driven decisions, and accelerates the transition towards a more sustainable built environment.

The presentation will include an interactive demonstration of the platform and provide practical guidance for leveraging LCA/PCF data for business growth and enhanced collaboration across the value chain.

Integrating Traceability Tools in LCA: A Pathway to Precise and Real-Time Primary Data Utilisation

Robert Pell, Andy Elmsley, Bertie O'Brien, Emma Lowe

Minviro, United Kingdom

The precision of Life Cycle Assessments (LCAS) critically depends on the quality and timeliness of the data used. This presentation introduces XYCLE, groundbreaking LCA software that integrates advanced traceability tools to collect and use real-time, primary data across extensive supply chains. XYCLE enhances data transparency and accuracy, offering stakeholders a dynamic platform to track environmental impacts accurately from the source to the end product.

By automating data capture and centralising data management, XYCLE reduces the traditional complexities associated with manual data collection and spreadsheet-based modelling, thereby enhancing the reliability of LCA outcomes. The software's robust traceability framework ensures that every dataset is meticulously tracked and verified, promoting better compliance and sustainability practices.

This talk will explore how XYCLE's innovative features streamline the LCA process and foster collaborative and informed decision-making, ultimately driving more sustainable industrial practices. We will explore the software's capabilities to transform LCA data into actionable insights, demonstrating its potential to revolutionise environmental assessments in various industries.

Further enhancing its utility, XYCLE offers a sophisticated Flow Model feature that allows users to refine their models iteratively, adjusting and optimising based on real-time data inputs. This capability is complemented by the Data Navigator, which provides complete visibility over the supply chain, tracing data from its origin through every transformation. This holistic approach ensures the integrity of the data and enables users to identify and act on opportunities for impact reduction effectively. Through detailed case studies and demonstrations, this presentation will illustrate how the integration of these technologies in XYCLE meets the growing demand for precise and scalable environmental performance tools.

TACK: A best-practice example of collaborative tools for associations

Margarida Gama[1], Abdessamad El Bahraoui[1], Pablo Englebienne[2], Janik Bollé[3]

[1]Sphera, Germany; [2]Afera, The Netherlands; [3]IVK, Germany

Afera and IVK commissioned Sphera to perform a project with the goal of setting up a tool for calculating cradle-to-gate product carbon footprints, following ISO 14067 and Together for Sustainability (TfS) guidelines for chemical products.

The tool, named TACK, includes two modules for calculating carbon footprints for adhesives and adhesive tapes. It is pre-verified and accessible to the Afera and IVK members, enabling performing intuitive PCF calculations of results for their products. The results provided by the tool can have different possible uses, such as communication and eco-design.

The set-up of the tool, including the collaboration between the two associations, Afera and IVK, as well as the features of the TACK tool and use cases will be presented and discussed.

Transforming Environmental Product Declarations through Digitalization and Scalability

Gaspard Phillis, trond Edvardsen, Mie Vold, Terje Tinbod, Ole Magnus Kolas Iversen

LCA.no AS, Norway

As industries navigate increasing sustainability requirements, Environmental Product Declarations (EPDs) have become essential for ensuring transparency and regulatory compliance. Traditional approaches to EPD development, characterized by static, manually intensive processes, face significant challenges in scalability and adaptability. At LCA.no, we are addressing these limitations through a digitalized, data-driven framework that advances the methodological boundaries of lifecycle assessment (LCA).

Our work focuses on transitioning from static, manually generated EPDs to dynamic EPDs produced directly by manufacturers using real-time production data. This paradigm shift is facilitated by cloud-based architectures and API integrations, enabling automated EPD generation for every product iteration on production lines. By integrating these capabilities, we address scalability challenges and enhance the accessibility of LCA practices while ensuring alignment with evolving regulations such as the Construction Product Regulation (CPR) and Digital Product Passport (DPP) frameworks.

A central feature of this system is the use of preverified data models, which streamline the verification process and ensure that dynamically generated EPDs are readily compliant with audit requirements. Additionally, AI-based control mechanisms are incorporated to support advanced quality assurance and reduce risks associated with human errors. This innovation is pivotal for maintaining accuracy and efficiency at scale, a necessity in the context of high-throughput manufacturing environments.

This presentation will elucidate the methodological advancements underlying our approach, emphasizing how digital tools enhance the rigor and scalability of EPD generation. By embedding real-time data and automation into the EPD process, our framework contributes to closing critical gaps in traditional LCA practices. The implications for sustainability reporting and regulatory compliance will be explored, showcasing how our system aligns with and supports broader industrial and environmental goals.

From Ideas to Action: Exploring the Automation of Life Cycle Assessment at ZEISS

Felix Maximilian Piontek, Ronja Kuhn, Michael Rodewald

Carl Zeiss AG, Germany

As the global emphasis and regulatory environment on sustainability intensifies, organizations are increasingly seeking efficient methodologies to assess their environmental impact. Life Cycle Assessment (LCA) serves as a critical tool in this endeavor, yet traditional approaches often face challenges in scalability and accuracy.

Our presentation outlines the journey of automating LCA processes at ZEISS, emphasizing the collaborative and exploratory phases.

Our journey commenced with internal and external brainstorming sessions aimed at identifying the relevant levers, challenges and potential ways forward. This laid the groundwork for a focused market research phase, where we analyzed existing LCA tools and methodologies to understand their functionalities, strengths, and weaknesses.

Following the market research, we entered an exploratory phase, which involved a comprehensive evaluation of different LCA tools available in the market. This phase included a deep dive into potentially applicable tool of various software solutions, assessing their capabilities in terms of data integration, user interface, and process automation.

The culmination of these efforts led to the decision to optimize our processes using publicly available and self-developed tools.

Through this structured journey of brainstorming, research, exploration, and implementation, we have laid a solid foundation for further advancements in LCA automation at ZEISS, positioning us to enhance our sustainability initiatives effectively.

Session 1.14: Communication and Raising Circular Economy Awareness via Robust LCA Part II

Time: Wednesday, 10/Sept/2025: 2:40pm - 4:10pm
Session Chair: Matthias Finkbeiner, Technische Universität Berlin, Germany
Session Chair: Stephane Morel, ESCP Business School, France

Applying the Regulatory Carbon Footprint Framework for Batteries: Insights from Renault's case study

Noura RAHBANI[1], Emilie Guilvert[1], Nadia CHIBANI[2], Yanlong ZHOU[2], Quentin NOGAREDE[3], Naeem ADIBI[1]

[1]WeLOOP, France; [2]Ampère, France; [3]Renault Group, France

As the EU Battery Regulation introduces stringent requirements for the carbon footprint of batteries, industries are tasked with aligning their practices with the yet-to-be-finalized regulatory Carbon Footprint Framework (CFF). While the final delegated act detailing the carbon footprint declaration requirements is still pending publication, Renault proactively initiated this Life Cycle Assessment (LCA) project with WeLOOP to prepare for and anticipate a range of potential scenarios that the final text might encompass. This project aimed to address regulatory challenges, highlight ambiguities in the framework, and evaluate the impacts of varying key parameters on carbon footprint outcomes, ensuring Renault is well-equipped to adapt to the finalized requirements.

The model developed during the project is highly parametrized, enabling Renault to anticipate a wide range of scenarios that could be reflected in the final regulatory text. This includes a configurable composition of the black mass entering the recycling process, allowing for detailed assessments of material recovery scenarios. The model also incorporates the integration of recycled materials into new battery cells, quantifying their contribution to footprint reductions. Parameters also enable switching between mass-based and economic allocation methods for impact distribution across co-products.

The study exposed different issues such as significant gaps between different LCA databases, lower variations of impacts on carbon footprint with high values of parameter R1 than expected. The project also tackled challenges such as ambiguities in the regulatory text and inconsistencies regarding the European Commission's targets.

The tool developed through this project is used not only to anticipate and meet the requirements of the Battery Regulation but also as a valuable resource for research and development initiatives. Additionally, it plays a key role in raising awareness among Renault's suppliers about the importance of carbon footprint reduction, fostering collaboration and innovation across the value chain to advance sustainable battery production methodologies in Europe.

From Concept to Circularity: Utilizing Data Integration and Life Cycle Assessment to Enhance Automotive Sustainability

Ann-Kathrin Briem[1], Sun Hea Hong[2], Shaoran Geng[2], Marie Schwahn[3], Christina Fischer[4]

[1]Fraunhofer Institute for Building Physics IBP; [2]University of Stuttgart, Institute for Acoustics and Building Physics IABP; [3]Fraunhofer Institute for Industrial Engineering IAO; [4]Schaeffler Technologies AG & Co. KG

This conference presentation highlights the key findings and methodologies derived from two interlinked research projects funded by the German Federal Ministry for Education and Research (BMBF) focused on enhancing sustainability in the automotive industry through life cycle assessment (LCA) and circular economy principles.

The Cyclometric project emphasizes the integration of LCA data with product design tools to facilitate a seamless data exchange that supports environmental impact assessments. Key achievements include the successful demonstration of data interfaces between LCA and a newly developed model-based systems engineering decision support tool ("Cyclo tool") for sustainable product development, using a passenger car centre console as an example. Challenges related to data quality, particularly concerning recycling processes, were identified, emphasising the need for the development of more robust datasets relevant to circular economy strategies to support accurate sustainability evaluations.

The EcoFrame project is one of currently four central research projects of ARENA2036, a collaborative research campus in Germany focused on automotive production. EcoFrame focuses on the principles of circular economy by addressing the interconnectedness of data across the automotive supply chain. It analyses the requirements for sustainability assessment methods, focusing on the integration of circularity aspects into product design and production processes. A value stream analysis is conducted to identify current barriers to circularity using the example of a tier-1 automotive component. The results provide critical insights into stakeholder perspectives and the need for improved data sharing.

Both projects consist of diverse consortia from industry and research. They contribute to a framework that enhances the understanding and application of sustainability assessments, facilitating a more informed decision-making process for stakeholders throughout the product life cycle. Ultimately, the findings aim to foster better integration of recycling strategies and sustainability evaluations in automotive design and manufacturing, paving the way for a more sustainable future in the industry.

LCA as a tool for creating a circularity roadmap for Finnish semiconductor industry

Noora Harju, Hanna Pihkola, Mona Arnold

VTT Technical Research Centre of Finland, Finland

The semiconductor industry forms the backbone of modern societies by providing advantageous technologies for instance for health care, energy and automotive industries. However, semiconductor manufacturing requires large amounts of resources, like energy and water, which causes significant environmental impacts that are accelerated by the growing demand of semiconductors, rapid innovation cycles and increased process complexity.

In this study, a Life Cycle Assessment (LCA) was conducted based on real data of a lab-scale cleanroom to identify hotspots of semiconductor manufacturing. Both the carbon footprint and the water footprint were included in the assessment. Water consumption is a critical issue especially in semiconductor manufacturing facilities in water-scarce areas. Furthermore, the aim was to scale up the results to high volume manufacturing so that these results can be compared with industrial processes. In sensitivity analysis, the geographical dimension, abatement efficiencies of fluorinated compounds and impact of varying die yields were explored.

To better understand the industry's perspective, Finnish companies in the semiconductor industry were

interviewed on how they interpret and utilize life cycle information. All in all, this study will provide information for creating a roadmap for sustainable Finnish semiconductor industry, aiming to address the areas of improvement based on the identified hotspots and find ways to turn the challenges into opportunities while increasing the degree of circularity in manufacturing processes. Additionally, the aim is to increase cooperation among value chain actors, as this is seen essential from the circularity perspective.

Modular circular system models for the assessment of R-strategy combinations: Example of footwear products

Meike Islamoglu, Sebastian Schawe, Philip Biessey, Manfred Renner

Ruhr University Bochum, Germany

The transition to a circular economy requires evaluating diverse circular strategies, known as R-strategies (e.g., repair, recycle), to guide stakeholders in identifying trade-offs and achieving sustainability goals. However, conventional tools such as Material Flow Analysis (MFA) and Life Cycle Assessment (LCA) are limited by their static nature, making it difficult to capture the dynamic interdependencies of circular systems, especially when comparing R-strategy combinations. System Dynamics (SD) modeling offers a promising complementary evaluation approach by integrating MFA and LCA insights into a dynamic framework capable of modeling feedback loops and non-linear behaviors, enabling a more holistic assessment of circular systems.

This study addresses two key challenges in modeling circular systems with SD: the lack of systematic comparison between R-strategy combinations and limited model transferability. To overcome these challenges, we employ a modular design to allow for the flexible activation and deactivation of R-strategies and enhance transferability by standardizing how interdependencies are defined and integrated. A single input form consolidates information on material composition and R-strategy parameters, such as recycling or refurbishment rates, ensuring the model can be easily adapted to different products.

The modular model is developed following the four model design steps identified in literature. In the first phase (problem definition and conceptualization), structural analysis is incorporated to identify the interdependencies among relevant R-strategies. In the second phase (model construction and testing), these interdependencies are parametrized and translated into a format suitable for integration into the input form, enabling their use in the simulation. The third phase (simulation and experimentation) applies the model to a case study of a circular shoe, validating the model's logic by exploring interactions among five R-strategies. Finally, in the fourth phase (analysis and interpretation), the model generates circularity and sustainability indicators to identify trade-offs and support decision-making in designing effective circular systems.

Towards a standardization of the physical durability assessment of clothing: lessons from the DURHABI project

Gaelle Courage[1], Romain Benkirane[2], Laurie Navarro[1], Carole Aubry Meneveau[1]

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Often associated with fast fashion, the Textile sector has led to a significant increase in the production, consumption and disposal of clothing [1]. The industry must quickly adopt new practices and decouple its growth from resource use. One of the first engaging strategies is to develop more durable items, designed to offer greater resilience, allowing them to be used and preserved for longer, and thereby requiring less frequent replacement and disposal. A way to reduce the quantity produced and marketed.

To be valid and scientifically rigorous, such a strategy must rely on an accurate assessment of the durability of articles. However, although many researchers have investigated this topic [2-7], no truly comprehen-

sive large-scale study has yet been conducted. To address this need, the collaborative applied research project DURHABI, supported by French ADEME Agency and eco-organization Refashion, was launched with the objective of developing a method for assessing the physical durability of twelve categories of fashion and home textiles.

Involving 80 brands (some on international territory), three laboratories, academic and professional structures, the study tested 10,000 pieces of 350 references over 60 maintenance cycles for a total of nearly 70,000-unit trials. The proposed deliverables:

- Provide recommendations suitable for durability assessment, including a selection of standardized tests, relevant care stages, and the operational conditions to be performed.
- Propose a calculation method for a physical durability score based on a range of requirement thresholds.
- Draw upon the results of an extensive national consumer survey which gathered 47,000 responses.
- Finally, the scope of this study allows us to rigorously feed different private, normative and governmental initiatives ; with the objective of achieving a harmonized and operational methodology, allowing industrialists to benefit from a reference framework for claiming their product longevity.

Within LCM, the project governance and proposed methodology will be presented.

Investigation on the use of LCA to assess business models in a circular economy context

Emilia Filippi, Monia Niero, Filippo Corsini, Marco Frey

Sant'Anna School of Advanced Studies, Pisa, Italy

Circular business models (CBMs) present a viable alternative to linear production systems, enabling companies to remain profitable while reducing their environmental impact. However, labelling a business model (BM) as "circular" does not necessarily guarantee greater sustainability. While CBMs can promote conservation mechanisms and sustainable consumption, they may also cause rebound effects (yielding only minor environmental benefits) or even backfire effects (where expected environmental benefits fail to materialise). Consequently, the environmental impacts of CBMs must be carefully assessed and monitored, with life cycle assessment (LCA) frequently employed for this purpose.

Recognising the growing need to evaluate CBMs' environmental effects, we conducted a review of 60 studies that applied LCA to assess CBMs. The first publication was released in 2007 and starting from 2014, publications have been consistent over time. Most studies are quantitative analyses; however, literature reviews, meta-analyses, and qualitative studies also emerged. The central role of LCA is evident: most quantitative studies rely on this approach alone or in combination with life cycle costing (LCC), qualitative and quantitative methods. The business model LCA, a new approach based on LCA and using economic performance as a comparative baseline, has also been applied. Most studies leverage life cycle-based methodologies to compare the environmental impacts of various BMs/CBMs or to analyse transitions from linear BMs to CBMs. Life cycle-based methodologies are also employed to evaluate the environmental impacts of individual CBMs or assess the environmental impacts when designing and implementing CBMs. Existing studies span all types of CBMs, with particular focus on use-oriented and result-oriented product-service systems, followed by CBMs extending product life and industrial symbiosis. Furthermore, the studies reveal significant sectoral diversity, with electrical and electronic equipment and clothing emerging as the most frequently analysed industries.

Session 1.15: LCM for the Biobased Economy: Innovative Methods and Practices Part I

Time: Wednesday, 10/Sept/2025: 2:40pm - 4:10pm
Session Chair: Thomas Schaubroeck, Luxembourg Institute of Science and Technology, Luxembourg
Session Chair: Tamara Coello García, Cesefor, Spain

Consequential LCA of alternative technological pathways for nitrogen recovery from municipal wastewater

Jade Müller-Carneiro[1], Lilla Simon[2], Ana Cordeiro[1], Bart Saerens[3], Lennert Dockx[3], Morten Birkved[2], Fausto Freire[1]

[1]University of Coimbra; [2]University of Southern Denmark; [3]Aquafin NV

New nutrient recovery (NR) technologies are being developed to recover nitrogen and phosphorus from wastewater treatment plants (WWTP) and produce secondary fertilizers for agriculture. Previous life cycle assessment (LCA) studies found environmental hotspots in NR systems, primarily related to energy and chemical inputs. Thus, identifying the most environmentally favorable NR pathways is critical. Consequential LCA aims to assess the environmental consequences of a decision, such as introducing a new technology into the existing technosphere, making it well-suited for evaluating emerging technologies. This LCA examines the impacts of transitioning from a conventional WWTP, based on conventional activated sludge (CAS), to two alternative NR pathways: (i) high-rate activated sludge followed by ion exchange/adsorption (HRAS-IEX) and (ii) ammonium stripping/scrubbing (SS). Conducted as part of the Horizon 2020 WalNUT project (https://walnutproject.eu/), this research assesses these NR processes at pilot scale operated by Aquafin in Flanders, Belgium. The current WWTP setup comprises primary treatment, secondary treatment (CAS), and anaerobic digestion (AD) of sludge. HRAS-IEX replaces CAS and recovers nitrogen from the HRAS effluent, while SS focuses solely on nitrogen recovery from AD reject water. Energy requirements are met through a Combined Heat and Power unit fueled by AD biogas, photovoltaics (PV), and grid electricity. The functional unit is defined as the average annual influent flow of 24,173,439 m^3 of wastewater, serving 171,000 population equivalent (PE). The life cycle inventory is based on primary data from the WWTP (collected over a 10-year period) and the two pilot plants (HRAS-IEX, SS) provided by Aquafin (co-authors). Secondary fertilizers (ammonium sulfate, used zeolite) are modeled to substitute inorganic fertilizer production. A comprehensive life cycle impact assessment (LCIA) is conducted using the Environmental Footprint v3.1 method. LCIA results are discussed, identifying environmental hotspots and highlighting trade-offs. Recommendations are provided to guide decision-makers in adopting and selecting environmentally sound NR technologies.

A critical Life Cycle Assessment approach for informed decision-making on bio-based material integration in Electrical and Electronic Equipment

Gabrielle LEGRAND, Noé SIONNEAU, Virginie RENAVANT

Schneider Electric, France

As part of the Eco Design methodology deployment, Schneider Electric is developing and implementing new practices aimed at accelerating the energy transition and minimizing the environmental impact of products throughout their life cycles. This sustainable development strategy emphasizes the integration of plastic composites formulated with recycled and/or bio-based resources, as well as the safest substances available. To facilitate environmentally conscious material selection, this study focuses on establishing a robust methodology for the consideration of life cycle assessment (LCA) data of bio-based polymer mate-

rials.

This work encompasses a comprehensive literature review on bio-based polymers, specifically bio-containing and bio-attributed types, alongside existing LCA methodologies. It critically evaluates Schneider Electric's current position on bio-based materials, clarifying the concepts of inclusion and exclusion of biogenic carbon in LCAs. The analysis examines various relevant environmental impacts, including climate change, water depletion, and land use, while contrasting bio-based materials with recycled materials.

The findings aim to provide valuable insights and actionable recommendations for the effective integration of bio-based polymers into Schneider Electric's sustainable development strategy, ultimately contributing to enhanced eco-design practices and a reduced environmental footprint.

Facilitating dynamic LCA and carbon footprint – precalculated datasets of an updated temporal database (DyPLCA) with a focus on wood-based products

Thomas Schaubroeck[1], Alya Bolowich[1], Tomás Navarrete Gutiérrez[1], Laurent Chion[1], Thomas Gibon[1], Kira Lancz[2], Massimo Pizzol[2], Tamara Coello[3], Eduardo Entrena-Barbero[4], Ligia Tiruta-Barna[5], Enrico Benetto[1]

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In the context of biobased systems, the dynamic carbon footprint approach differentiates greenhouse gas emissions over time, thus better characterizing the resulting impact and corresponding potential benefits over fossil-based alternatives. By extension, the entire field of dynamic LCA, focusing on time-differentiation, is of importance for impact categories beyond that of climate change (e.g. toxicity) and time-dependent inventory processes (e.g. agricultural seasonality or an electricity mix adjusting due to demand). A fully temporalized foreground and background life cycle inventory has been developed through the DyPLCA framework, and this includes temporal parameters for all ecoinvent 3.10 processes. In this presentation, we will address two challenging aspects for dynamic LCA: the lack of detailed data, especially for forestry processes, and the high computational demand that comes with the complexity of dynamic LCA models (e.g. a single run of DyPLCA with >90% of flow coverage can take 5 hours). To address these challenges, the objectives of this research are to (1) update the DyPLCA database with specifically better data for the forest sector; (2) pre-calculate and distribute normalized life cycle inventories, notably CO2 emissions, over time for various processes, and (3) illustrate DyPLCA with a case study on wood products. For the first objective, LIST will further update the DyPLCA database by completing temporal parameter data for ecoinvent 3.11 processes. Moreover, in case of forest processes, we will apprehend the Carbon flux Forest model of Aalborg University, which provides CO2 profiles for different forest species under different management at various locations. To produce temporal profiles for all ecoinvent processes, LIST will run the DyPLCA model using high performance computing. Finally, we will perform a dynamic carbon footprint of Laminated Strand Lumber to show the difference between standard and dynamic LCA. This research is part of the EU-funded LCA4BIO project (n° 101135371).

Environmental and Economic Assessment of Conventional and New Generation Olefin Production Routes in Modern Refineries

Semra Bakkaloglu[1], Aurora Cavaliere[2], Andrea Paulillo[2], Massimiliano Materazzi[2], Nilay Shah[1]

[1]Department of Chemical Engineering, Imperial College London, United Kingdom; [2]Department of Chemical Engineering, University College London, United Kingdom

The refinery industry plays a pivotal role in global economy, providing a secure supply of feedstocks for the chemical and manufacturing sectors. Through the transformation of manufacturing processes and the introduction of renewable feedstocks, refineries are well placed to decarbonise their own activities and products and to support other sectors in decarbonising operations, while developing new energy technologies such as hydrogen supply, energy storage and CCUS. Bio-based chemicals, such as bio-olefins, could play a key part in a sustainable, low-carbon refinery sector, in combination with higher process efficiencies, recycling and the pursuit of other sustainability characteristics, such as low toxicity. They also offer the opportunity to generate low-carbon energy at the end of the useful life cycle of a product or even act as a carbon store.

This project introduces a novel olefin synthesis process designed to operate efficiently with CO2-rich feedstocks, such as syngas derived from biomass gasification. In particular, the sorption-enhanced olefin synthesis (SEOS) technology combines multiple steps to convert syngas to olefins within the same reactor through in-situ water removal and a cyclic regeneration process.

This study evaluates the environmental and economic performance of six distinct olefin production routes from a cradle-to-gate analysis, benchmarking them against SEOS technology. Environmental impacts—including climate change over a 100-year horizon, resource consumption, acidification, eutrophication, land use, toxicity, ozone depletion, particulate matter, resource use and water use—are assessed. Additionally, a life cycle cost (LCC) analysis identifies key cost drivers and hotspots, enabling a comparative assessment of the economic viability of the proposed process.

The results highlight critical environmental and economic considerations across the production chain, from biomass feedstock acquisition to olefin synthesis. The findings demonstrate SEOS technologies can offer a more sustainable and economically competitive alternative to traditional fossil-based olefin production methods, paving the way for a greener chemical industry.

Competitiveness analysis to develop a marginal mix for consequential LCA: A Seaweed Case Study

Ravalnath Vijay Shikhare, Massimo Pizzol, Ning An

Aalborg University, Denmark

Identifying marginal suppliers is crucial in consequential Life Cycle Assessment (LCA), as supplier changes significantly affect environmental impact outcomes. This study proposes using economic competitiveness to enhance the identification of marginal suppliers. Competitiveness reflects a supplier's ability to meet market demands while outperforming others. Two economic methods are applied: Revealed Comparative Advantage (RCA) and the Linear Approximate Almost Ideal Demand (LA-AIDS) model, focusing on seaweed as a commodity due to its importance in the blue bioeconomy, versatile applications, and lack of reliable production data often needed for LCA.

RCA assesses competitiveness of countries exporting seaweed to China, using historical trade data from the BACI database. China is a significant case study due to its dominance in global seaweed production and increasing demand, positioning it as the largest importer and a key player in global trade. RCA results highlight Philippines, South Korea, Tanzania, Indonesia, Chile, Peru, and Madagascar as competitive exporters to China. However, RCA's qualitative nature limits its ability to determine marginal supplier mixes.

The LA-AIDS model estimates demand elasticities and marginal share identifying Chile, Indonesia, Peru,

and South Korea, having positive elasticity values and are likely to expand market share with increased Chinese demand. Conversely, Philippines and RoW show negative elasticities, indicating difficulties in meeting future demand. These economic methods offer a comprehensive framework to predict marginal supplier shifts based solely on trade data, avoiding the need for historical production volumes.

This integrated approach also provides critical insights into the competitive dynamics among seaweed-exporting countries. It highlights the potential of RCA and LA-AIDS model to address key limitations in existing LCA methods, such as intense data requirements, scalability, and robustness. Ultimately, this study contributes to advancing consequential LCA by offering a robust method for identifying marginal suppliers based on economic and trade data.

From residual biomass to bio-based products and molecules at country scale: where to focus for high impact in a jungle of possibilities.

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Transitioning from fossil-based to bio-based economies requires additional biomass consumption. Favouring underused streams waste and co-products, seen as a sustainable alternative to dedicated crops, could minimize land competition. However, the potential environmental performance must be evaluated through a robust method such as life cycle assessment (LCA) before deciding on the best use of this residual biomass. Given the data-intensive nature of LCA, researchers may need to limit the number of systems studied.

This study focuses on a wide array of biobased materials and chemicals produced from residual biomasses. We introduce a comprehensive selection method for identifying promising conversion pathways, in terms of environmental performance, prior to conducting a full state-of-the-art LCA. This prioritization method enables targeted LCA efforts, reducing complexity while facilitating detailed scenario analysis to drive more effective decision-making. The method is here applied at the scale of France and aims at identifying which final products are to be prioritized for large-scale implementation from the pool of residual biomasses available.

The approach developed herein relies on a combination of key datasets related to current and alternative production routes: (1) An analysis of the environmental impact of products based on environmentally extended input-output tables from Exiobase; (2) The exchanged physical volumes in tons (production and demand) retrieved from national statistics and literature; (3) Specific criteria such as evidence of the existence of biobased pathways and their technological readiness level. For molecules, platform molecules at the basis of several derivatives were also prioritized; (4) The suitability of the residual biomass available from the territory under study for the bio-based pathways previously identified.

Assessing the biogenic carbon dynamics of wood-based products

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Copernicus Institute of Sustainable Development, Utrecht University, The Netherlands

Bio-based systems offer significant sustainability potential, with harvested wood and wood-based products (HWPs) playing a key role in mitigating climate change through biogenic carbon storage. Assessing their environmental performance requires accounting for biogenic carbon, which is influenced by the spatiotemporal dynamics of carbon fluxes, which depend on climate, land use, soil types, and forest management, over time.

While Life Cycle Assessment (LCA) is commonly used to evaluate wood-based products, conventional

LCAs often overlook these temporal and spatial factors. Conventional LCAs meet its limit to capture the dynamic nature of environmental systems. Dynamic LCA (DLCA) tries to address static limitations by incorporating temporal, spatial, and spatiotemporal factors. DLCA for wood-based products can, for example, include time-dependent changes in carbon storage, emissions, and sequestration, considering forest growth, harvest, regrowth, and regional factors like management practices and climate. Despite its potential, DLCA still needs to be validated due to the limited number of DLCA studies applied to wood-based systems.

This study proposes and explores a dynamic LCA framework to better capture carbon dynamics in HWPs. We apply this approach to a case study on pulp production in Austria and Brazil, comparing scenarios under different methodological assumptions as time horizon, and temporal and spatial resolution. With this, we aim to gain insights into the added value over static LCA, and assess how varying model choices affect carbon impact outcomes of HWPs.

Life-cycle assessment of Ferromanganese production using biocarbon as reductant and carbon capture and storage

Marvin Werra[1], Marcos Watanabe[1], Vedant Ballal[1], Teymur Gogiyev[1], Sten Yngve Larsen[2], Merete Tangstad[1], Øyvind Skreiberg[3], Francesco Cherubini[1]

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Ferromanganese (FeMn) is an essential alloy whose production is currently dependent on metallurgical coke as a reducing agent, resulting in carbon dioxide emissions that are hard-to-abate. The use of biocarbon as an alternative reductant and carbon capture and storage (CCS) are key mitigation strategies of FeMn production, yet their environmental performances are still unexplored. This study evaluates the possible environmental co-benefits and trade-offs of replacing metallurgical coke with biocarbon, with and without CCS, in Norway. The climate impact of FeMn production is 2312 ± 110 kg CO2-equivalents per tonne of alloy (mean ± 5th/95th percentiles). Emission reductions are about 57 ± 3.0% at a full substitution rate and 29 ± 3.7% at a more realistic substitution rate of 50%. CCS alone can reduce emissions of 53 ± 4.8%. The combination of biocarbon with CCS can achieve negative emissions when the biocarbon substitution is higher than 78%. Process optimisation throughout the value chain is key to maximise climate benefits. The main trade-offs can occur with terrestrial acidification and particulate matter formation, and are mostly due to biomass pyrolysis. A 50% substitution of the metallurgical coke annually used for FeMn production in Norway requires around 25% of currently unused forest residues, or 8% of the today's wood harvest volume. Although some economic and technological barriers remain to be overcome, this study offers an initial quantification of the environmental implications that can be expected from a value chain perspective in connection to local resource availability and technical challenges.

Analysis of changes in industrial structure by the shift from fossil resources to bio-derived resources

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To advance a bio-based and sustainable economy, it is necessary to clarify the impacts that the shift from traditional fossil resources to bio-derived resources will have on the socio-economy and supply chains.

In this study, we use input-output analysis, which can analyze changes in structure of industrial production, added value creation, and economic circulation due to the introduction of technology, to analyze the socio-economy impacts of the shift to bio-derived resources. Specifically, we focused on cellulose nanofiber

(CNF) technology and compared it with existing resin products derived from fossil resources. We create an input-output table that can analyze the effects of introducing CNF based on the process information. In addition, we use regional input-output tables at the municipal level in Japan to present the differences in socio-economic impacts due to the introduction of CNF technology using several indicators. Furthermore, we use a multi-regional input-output table in the world to analyze the impacts that resource shifts may have on the global supply chain.

The results of this study were able to quantitatively show that the shift from fossil resources to bio-derived resources not only strengthens the connections between the primary, secondary, and tertiary industries, but also builds supply chains in regions different from the supply chains of fossil resources. In addition, with regard to the impacts on regional socio-economy, it became clear that the regions in which technology should be introduced will differ depending on the purpose of technology design and introduction, such as maximizing production efficiency, production scale, and economic effects, equalizing the effects, and maintaining the population tolerance of depopulated regions, due to differences in regional economic and industrial structures. These results provide important information for promoting the bioeconomy, such as the impact of resource shift on industry in advance and socio-economic evaluation of technology.

Session 1.16: LCA & LCM for Improved Energy Decision-Making Part I

Time: Wednesday, 10/Sept/2025: 2:40pm - 4:10pm
Session Chair: Luka Smajila, KTH - Royal Institute of Technology, Sweden
Session Chair: Ketan Vaidya, ex-Northvolt AB, Sweden

Time-aware life cycle inventories for electricity consumption

Sabina Bednářová, Thomas Gibon, Enrico Benetto

Luxembourg Institute of Science and Technology, Luxembourg

Rapid changes in electricity supply patterns, driven by the increasing share of renewable sources and international exchanges, can lead to misrepresentations in life cycle inventories (LCI) of electricity mixes. In turn, this may yield flawed life cycle impact assessment (LCIA) results, particularly for electricity-intensive systems, and incompatibility with recent GHG reporting directives.

LCI databases, such as ecoinvent, typically rely on annual averages from [year n-3], failing to capture recent variations in electricity production throughout the year. With intermittent electricity generation, production mixes vary significantly by hour, month, or season. Combined with fluctuating consumption, reliance on average mixes distorts impact estimates. Contrary to the notion that variability represents ontic uncertainty, we argue it can be systematically captured to improve result reliability, reduce uncertainty, and optimize studied systems.

This study addresses this gap by introducing a Python package, shrecc (Simple Hourly Electricity Consumption Calculation), which gathers high-resolution hourly electricity production and consumption data via the "Energy Charts" API. The data is matched with ecoinvent classifications using ENTSO-E datasets, converted to low-voltage consumption mixes, and made available as a ready-to-use brightway-compatible database. Practitioners can select European countries and time intervals (one-off or recurring), enabling precise integration into LCA models.

We demonstrate the tool's impact through an LCA of an electric agricultural robot operated for 15 years in France and Greece. The robot, charged daily for one hour at different times, was modeled using brightway with time-specific electricity LCIs produced by shrecc. We compared LCIA results for specific charging hours (8 am and 10 pm) versus the annual mix for carbon-intensive and low-carbon electricity scenarios. Time-specific electricity LCIs consistently resulted in lower LCIA scores across both countries and six impact categories, underscoring the importance of using time-specific electricity LCIs in LCA studies.

Serious Energy System Gaming

Joern Hartung[1], Ingo Bernsdorf[1], Lisa Schmidtfall[2]

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Life cycle assessment is a fundament of the multi-criteria assessment of energy systems, like in DIN SPEC 91432. Based on this framework, the ENSURE project is developing a Serious Energy System Game which will convey the (un)expected interrelationships of the energy transition, the functioning of energy grid structures, and the systemic interaction of various technological components. The heart is an interactive table featuring 24 different objects.

The "Energy Flow" game focuses on interactively setting up and decarbonizing an individual energy system using various technologies while addressing the interactions with grid operation. The audience is faced with an authentic area and load- and generation profiles for one authentic and changeable saison week and

will gradually set up and adapt electricity generators, consumers, and grid infrastructure to ensure reliable operation.

The next step involves decarbonizing the energy supply by expanding renewable electricity generation with wind power and photovoltaics. This decarbonization continues with the electrification of heating, transport, and production processes to reduce the environmental impact category global warming in CO2 emissions.

The increasing demand for electricity necessitates the expansion of renewable power generation and grid capacities and this increases resource scarcity as a second environmental impact category.

The Serious Energy System Gaming supports the decision-making in Energy by providing an interactive realtime simulation to the stakeholder so that they can make decisions and instantaneously check and discuss the impacts like burden shifting on other objects or environmental indicators. This helps to to avoid planning issues like “not invented here” and individual optima against system optima.

The interactive presentation of “Energy Flow” with an active part of the audience will give the chance to point out crucial learnings of how to make complex topics like LCA and Energy understandable and thus interesting.

Prediction and assessment methods for sustainable solar energy systems within our planetary boundaries: How reliable are they?

Natalia Cano-Londoño, Rebecca Saive, Tim Bekius, Laura Franco-García

University of Twente, Netherlands.

Solar energy encounters various technological, environmental, social, and economic challenges that must be addressed to ensure its operation within safe planetary boundaries. This study presents a critical analysis of the sustainability of solar energy systems within the planetary boundaries framework, which sets the limits within which humanity can safely operate. Given the substantial contribution of the energy sector to global greenhouse gas emissions, solar energy has emerged as a crucial element in the shift towards a sustainable energy future. Nevertheless, numerous challenges impede solar energy systems reaching optimal effectiveness, encompassing technological and methodological sustainable tools constraints, environmental impacts, and socio-economic implications. This research aims to comprehensively assess these challenges and propose strategies to surmount them through applying a Life Cycle Sustainability Assessment (LCSA) approach. The primary research question addressed is, “How reliable are the predictive and anticipatory assessment methods for sustainable solar energy systems within our planetary boundaries?” The study integrated circular economy principles, criticality evaluation, and advanced technological tools to enhance solar energy systems’ efficiency, environmental performance, and socio-economic benefits. By addressing the entire life cycle of solar technologies—from material extraction to end-of-life (cradle-to grave) —this work seeks to contribute to developing more sustainable solar energy systems that operate within the safe limits of our planet’s boundaries. The findings highlight the need for a holistic approach that not only focuses on technological advancements but also considers the broader environmental and socio-economic impacts to ensure a truly sustainable energy transition.

Keywords: Solar energy, planetary boundaries, life cycle sustainability assessment, circular economy evaluation, criticality evaluation.

Exploring LCA electricity modelling paradigms in Europe: combining the location-based and market-based approaches?

Anne Bouter[1], Romain Besseau[1], Thomas Gibon[2]

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Transitioning to a low-carbon economy necessitates informed decision-making, particularly in assessing the environmental impacts of electricity consumption. To that end, Life-Cycle Assessment (LCA) has a critical role to play. However, multiple modelling approaches for electricity consumption coexist in current environmental accounting frameworks, which can produce divergent results and opposite conclusions.

Various guidelines for modelling electricity consumption in LCA currently differ in their underlying methodologies, either focusing on physical energy flows, or relying on contractual instruments as Energy Attribute Certificates (EACs).

This study compares the environmental impacts of the European electricity system over one year, through a location-based and a market-based approach. The first approach relies on ENTSO-E hourly data of production and exchange of electricity and a physical tracking algorithm, while the market-based approach relies on EACs in Europe: Guarantees of Origin (GOs), provided by the Association of Issuing Bodies.

Results obtained for European countries show that using GOs can lead to a decoupling of contractual instruments and physical energy flows both in time and space. This potentially results in over- or under-attribution of renewable energy sources as observed for Sweden and Germany, respectively among the largest net exporters and importers of GOs. Furthermore, data on the age of installations generating certified electricity in some countries raise questions about the effectiveness of GOs in promoting additional renewable/low-carbon energy sources.

Potential limitations and challenges of both approaches, including potential market distortion or double counting will then be discussed. Finally, we will explore a way to reconcile both approaches by analysing the intersection of physical and economic realities.

Our findings are essential for policymakers and industry stakeholders seeking to accurately assess electricity consumption's environmental impacts. Bridging the gap on LCA electricity modelling approaches, we will tend to ensure a more transparent and effective transition to a low-carbon economy.

Harnessing Life Cycle Assessment to Enhance Competitiveness in Steel Industry: Challenges and Opportunities in Transitioning to Renewable Energy

Natalia Susanto Salim, Jessica Hanafi, Gloria FJ Kartikasari, Vivian Bong

Life Cycle Indonesia

The construction sector faces increasing scrutiny for its environmental practices due to stricter global regulations. In Indonesia, the construction sector accounted for 9.92% of GDP in 2023, with the metal industry growing 10.85% year-over-year in Q3 2023. Rising global demand for steel products with Environmental Product Declarations (EPDs), CBAM, and other carbon regulations require Indonesian manufacturers to assess their environmental impacts to remain competitive. Steel production, being energy-intensive, necessitates Life Cycle Assessment (LCA) to benchmark environmental performance and identify potential improvement. This study examines Indonesian steel products' EPD results to explore challenges and opportunities for transitioning to renewable energy and enhancing competitiveness.

The study analyzes LCA results for steel products based on 100 EPDs from Asia, Europe, and other regions, accessed via the International EPD System in 2022. It emphasizes embedded carbon emissions across A1-A3 modules (raw material extraction, transportation, and production). Data on flat products and billets in Indonesia were included, comparing Basic Oxygen Furnace (BOF) and Electric Arc Furnace (EAF) technolo-

gies.

Global average steel product emissions are approximately 2.01E+03 kg CO2 eq/ton. A case study on Indonesian flat products shows competitive emissions, comparable to BOF-based production. Although EAF technology has been implemented in several cases, the dependency on coal in the Indonesian electricity mix negates the EAF's environmental advantages. Scenario analysis illustrates how energy mix adjustments could improve competitiveness by reducing GHG impacts.

Accelerating the renewable energy transition is crucial for competitiveness. Aligning with global zero-coal initiatives offers environmental and economic benefits while fostering domestic growth. Investments in renewable infrastructure and supportive policies are critical. This study demonstrates the value of LCA in decision-making for energy-intensive industries. Optimizing energy sources and addressing lifecycle hotspots through resource efficiency and cleaner production will help Indonesia's steel industry align with global sustainability goals and build resilience.

Considering risk-related impacts of the hydrogen industry in a life-cycle perspective: a systematic review

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One solution envisioned to reduce the anthropogenic pressure on climate, and eventually meet the needs of the NZE scenario, is to develop massively the low-carbon hydrogen industry (IEA 2024). As of today, low-carbon hydrogen represents 1% of the global production, whereas it should represent more than 95% to achieve the NZE ambitions (IEA 2024). Yet such deployment rates would require special attention for decision makers. Indeed, given the specificities of the hydrogen industry, sustainability assessment methods, such as Life Cycle Assessment (LCA) and Risk Analysis (RA), have key roles to play in the decision-making process. Until now, both methodologies have been developed and used for distinguished purposes: respectively environmental impact assessments and safety cases. We believe it is necessary to broaden the scope of impact assessment as standardized LCA does not cover the whole spectrum of potential environmental damages that could be induced by the hydrogen industry: chronical risks (leakage, membrane degradation in fuel cells, …) and exceptional risks (accident, sabotage, natural disaster, …). These risks may induce environmental impacts, e.g. hydrogen fugitive emissions have an indirect negative impact on climate change (Sand 2023), as well as safety issues – quantifying their occurrence and their consequences would provide enriched environmental assessment.

Facing those concerns, a systematic literature review has been carried out, notably to better understand how chronical and exceptional risks are accounted for in different methodologies. The goal of this study is to facilitate future integration of impacts related to "unexpected" events into environmental studies. The review identified a large lexical field referring to the different kinds of risks, that will be presented and discussed. Furthermore, insights and guidelines on the treatment of chronical risks in LCAs (as background data, as a sensibility parameter, as uncertainty, …) will be provided.

Sustainable Power-to-X Development in South Africa

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The transition to low-carbon fuels is essential for decarbonising global energy systems. South Africa's abundant renewable solar and wind resources make it a prime location for Power-to-X (PtX) and the production of green hydrogen and other derivatives. However, ensuring the sustainability of PtX developments requires careful project design and ex-ante assessment to minimise impacts. This study proposes an integrated planning and assessment process, combining spatial planning with environmental and social Life Cycle Assessments (LCAs) to guide PtX developments towards a just energy transition and sustainable development.

A prospective outlook of PtX development in South Africa until 2050 was formulated in accordance with national policy goals and targets. A landscape spatial planning tool identified optimal sites for PtX development by applying a mitigation hierarchy that minimises land-use conflicts and other environmental, economic, and social impacts. The avoidance of existing agriculture and conservation areas mitigates many impacts, but could diminish and fragment the land available for renewable energy infrastructure. The complementary environmental LCA revealed that PtX derivatives can be produced with a carbon intensity well within proposed international thresholds for the certification of green hydrogen, and achieving South Africa's 2050 target of 4.7 million tonnes of green hydrogen will reduce annual carbon emissions by 112 million tonnes of carbon dioxide equivalents. Furthermore, the recycling renewable energy infrastructure reduces embodied emissions of PtX, while minimising resource depletion and recovering valuable raw materials to support the circular economy. The social LCA highlighted the importance of aligning PtX projects with local development contexts to address social inequalities and the need for employment, skills, and economic growth. Judicious planning and governance is needed to balance the economic opportunities and global climate mitigation benefits associated with PtX exports, with the local use of PtX and associated local economic development benefits.

Comparative Analysis of Life Cycle Assessment (LCA) and RED III Methodologies for GHG Emissions in the Ammonia Value Chain

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The EU's Green Deal targets producing 10 million tonnes of renewable hydrogen and importing 10 million tonnes by 2030. The most likely regions from which the EU will import its renewable hydrogen are the Middle East and North Africa, as they are relatively close to Europe and have a high potential for producing renewable hydrogen from solar power plants. One of the challenges in this ambitious plan is the transportation of hydrogen. A potential solution is to use ammonia as an energy carrier for hydrogen.

The EU-funded SINGLE project is investigating the use of the ammonia value chain as a hydrogen carrier. The value chain is generic and consists of generic building blocks that include various transportation and storage technologies at different scales to evaluate a wide range of possibilities. The value chain includes hydrogen production with electrolyzers, ammonia production with the Haber-Bosch process, transportation via pipeline, train, and tanker, small- and large-scale storage, and an ammonia cracking process with Proton Ceramic Electrochemical Reactor.

For hydrogen to be considered renewable in the EU, its GHG emissions at the end user must be below 3.384 kg CO2-eq./kgH2. This threshold is set out in the Renewable Energy Directive (RED) III, which also defines a methodology for calculating the GHG emissions of hydrogen. The RED III methodology is similar to the standardised life cycle assessment (LCA) methodology, but there are some key differences between

the methodologies.

In the study, we calculated the GHG emissions of hydrogen - which is transported to the end consumer via the ammonia value chain - using both methodologies. The results show the main differences between the methodologies, namely (i) different accounting of upstream emissions from renewable energy sources, (ii) different scope of upstream system boundaries for fossil energy sources, (iii) different GWP-100 values used in the methodology.

Lifecycle management based on regional demonstration; Case study of thermal energy storage system with adsorbent utilizing low-temperature waste heat

Yoshiaki Kawakami, Takamasa Oyama, Haruyuki Kamata, Masayuki Tanino

Takasago Thermal Engineering Co.,Ltd., Japan

As well as electricity, decarbonization of heat is also urgently needed, but many heat-related technologies are emerging and are technically extremely complex, involving temperature changes and chemical reactions, and are not well understood by the public. Therefore, lifecycle management combined with regional demonstrations will be an important key enabler for their deployment.

Adsorbent materials, which are thermal energy storage materials, have the property of generating heat when moisture is captured. Using this phenomenon, removal of moisture and the heat generation are achieved by introducing moist air into the adsorbent, and hot air for air conditioning or dry air for industrial processes can be supplied to the demand side. On the other hand, if the adsorbent is transported to a waste heat source, the waste heat can be used to dry the adsorbent (i.e. removal of captured moisture). This means that waste heat can be stored into the material. Furthermore, this method allows more thermal energy to be stored and used than conventional methods using latent heat or sensible heat, with less energy loss. If this thermal energy storage and transportation system is introduced, it will enable the effective use of unused local resources even in areas where the district heating system is not well developed.

A commercial-scale demonstration test of a thermal energy storage and transportation system using 2 to 5 tons of adsorbent that connects waste heat from local industry with neighbor heat demand sites was planned and conducted throughout the year in a regional city in Japan, to improve its technology readiness level, assess its life cycle environmental impact, and evaluate its cost in cooperation with local industries and municipalities.

Session 1.17: Textile/Apparel: B2B & B2C Communication Challenges

Time: Wednesday, 10/Sept/2025: 2:40pm - 4:10pm
Session Chair: Enrico Benetto, Luxembourg Institute of Science and Technology, Luxembourg
Session Chair: Federico Brugnoli, SPIN360, Italy

Social Product Declaration (SPD) and Social Product Declaration-Product Category Rules (SPD-PCR) for cotton products

Mario Alessi[2], Shammas Saleem[2], Heinz Zeller[1], Antonio Covais[2]

[1]Hugo Boss; [2]Circular s.r.l

The objective of this research is to advance social sustainability within the cotton industry through the development and implementation of the Social Product Declaration (SPD) and the Social Product Declaration Product Category Rules (SPD-PCR) for cotton-based products. The work is conducted by Hugo Boss and Stichting Raddis, with technical and scientific support provided by Circular s.r.l. The initiative applies the Social Life Cycle Assessment (S-LCA) methodology, following the guidelines established by ISO 14075:2024 and the UNEP 2020 framework, and for the communication the SPD scheme will be used. The presentation will give an overview of the work pachages of the project as well as the current state of the art of the social lca applied to Cotton in literature.

A central component of the research will be the collection of primary data to evaluate the social impacts of cotton products across their entire life cycle, facilitated through the design and application of tailored questionnaires. Primary data will be sourced from Hugo Boss, Stichting Raddis, suppliers, and local communities, whereas secondary data will be derived from sustainability reports and academic literature. Particular emphasis is placed on vulnerable stakeholder groups, such as workers and local populations, in order to ensure a comprehensive assessment of both social risks and benefits. For doing it, a specific questionnaire will be presented together with the logic used to define reference values.

Furthermore, the research aims to develop product category rules (PCRs) for social products that complement existing Environmental Product Declarations (EPDs), thereby facilitating an integrated assessment of both social and environmental sustainability dimensions. Circular s.r.l will also present its experience on the process development for Social Product Declaration (SPD) and the Social Product Declaration Product Category Rules (SPD-PCR).

Analysing the climate impacts of selected SME fashion business models in Europe

Essi Paronen, Eveliina Hylkilä, Silvia Forin, Annu Markkula

VTT Technical Research Centre of Finland, Finland

Introduction: The European Commission has set a goal to reduce the climate impacts of various sectors, including textiles and fashion. As part of the Creative and Cultural Sectors and Industries (CCSI), the textile and fashion sector has the potential to act as a driver in the EU's sustainable climate transition. The EU project CRAFT-IT4SD (Craft Revitalization Action for Future-proofing the Transition to Innovative Technologies for Sustainable Development) aims to unlock the potential of the CCSIs in this transition. In the project, the climate impacts of chosen fashion business model cases are assessed by applying Life Cycle Assessment (LCA). The goal is to determine how these cases can promote and facilitate sustainable climate

transition.

Materials and methods: The LCA is performed for different fashion companies in Denmark, Spain, Finland and Romania. The LCA methodology is applied to the business models to estimate their climate impacts. The cases represent different sustainable approaches to business models. The cases focus on for example the reuse of deadstock fabric in production, clothing rental and tailor-made products. The climate impacts of each case are compared to traditional business model alternatives in the fashion sector.

Results and discussion: The analysis of the LCA case studies is ongoing. The results will be reported by June 2025 and they will be available when the conference takes place. The findings will be described and discussed further in the conference presentation.

Conclusion: Quantitative evidence from the LCA is needed to better understand the potential of different sustainable business models in advancing sustainable climate transition, and to support textile and fashion companies in aligning their actions with the EU's climate targets. The LCA findings of this study will provide insights relevant to other sectors as well, for developing the sustainability of business models.

End-of-life label to support makers' decision to measure circularity in the textile industry.

Kryssian Romeiro Cascione[1], Veeriah Jegatheesan[3], Lúcio Cardozo Filho[2], José Augusto de Oliveira[1]

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The textile industry is a major global production sector driven by high consumer demand, especially from fast fashion, which leads to frequent collections and rapid product turnover. Various industries, including textiles, are adapting to the principles of the Circular Economy, acknowledging the finite nature of natural resources. This approach aims to close product life cycles to sustain the biosphere's carrying capacity and the global economy. For this purpose, it is essential to implement product end-of-life (EoL) strategies. Despite its relevance, the textile industry still lacks metrics for assessing the environmental performance of the various stages in the product's life cycles, particularly at the EoL, the environmental performance of product life cycle stages is a strategic requirement for a globalized and competitive market. To measure this performance, life cycle assessment (LCA) is a tool with significant potential for generating comparisons across processes and products. The project develops a label that uses LCA to calculate the environmental performance based on parameters such as carbon footprint, climate change, ozone depletion, human toxicity, ecotoxicity, and the use of land, water, and fossil resources, among others, for the eight EoL stages of a textile product. It provides information about each EoL stage and identifies which one has the best environmental performance, enabling comparisons between them, and supporting decision-making in the textile sector to improve circularity. The result is a quantitative tool with both micro and macro-outputs to support both Business-to-Business (B2B) and Business-to-Consumer (B2C) decision-makers' regarding the best strategies and methods for disposing of textile goods, providing information and accountability for both sides of the textile chain, producers and consumers.

From Garment to Wardrobe: Rethinking the Functional Unit in Life Cycle Assessment of Apparel.

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Apparel companies face challenges communicating about environmental impacts amid greenwashing concerns and evolving regulations. While Life Cycle Assessment (LCA) is a key methodology for evaluating these impacts, most studies use a product-based functional unit (FU) to calculate a garment's overall impact, which can be misleading as total impact increases with longer use. Shifting to "impact per wear" as the FU offers a more nuanced perspective but remains limited to individual products. To assess overall apparel consumption and strategies like reuse or rental, Piontek et al. (2019) propose "one year of varied use of clothing" as the FU to account for the different usage patterns and lifespans of clothing. Here, the focus is on one person and, therefore, their entire wardrobe instead of a single product. Yet, its application remains underdeveloped. This is partly due to a lack of data on the use phase of clothing, which is often oversimplified in LCA studies. It is either neglected (cradle-to-gate), reliant on poor proxy data, or based on rough estimates. Consumer behavior, including garment lifespans and care practices, remains poorly characterized despite its significant influence on environmental outcomes.

To address this, (1) consumer use behavior is characterized, and (2) reference streams for a user-based FU are defined. A wardrobe study, consisting of at-home interviews, gathered primary data on the quantity, usage patterns, and lifespans of clothing items with individuals. Additionally, further wardrobe studies focused on individuals engaged in reuse or rental. Compiling these data informs the development of evidence-based reference streams for the proposed FU: a baseline representing an average individual's clothing usage and several alternative streams showing how strategies like reducing, reusing, or renting may affect it. Conducting LCA studies using this functional unit offers more nuanced results to apparel companies seeking to communicate their products or services' environmental impacts in earnest.

Reweaving the Waste Hierarchy: Europe's Textile Challenge

Matilda Lidfeldt, Maja Nellström, Amanda Martvall, Gustav Sandin, Simone Andersson

IVL Swedish Environmental Research Institute, Sweden

Today, large quantities of used textiles are not collected. Instead they end up as household waste that are eventually subjected to incineration or landfill. However, from January 1, 2025, separate textile collection is required in all EU member states through an update in the EU Waste Framework Directive. Through the new legislation, the quantity of collected textiles is expected to increase resulting in more textiles being subjected to the options included in the waste hierarchy; reuse, recycling, incineration. The waste hierarchy identifies reuse as more favourable than recycling. However, the export of textiles for reuse in developing countries has drawn criticism, particularly related to poor waste management. This critique has sparked debates about the validity of the waste hierarchy's prioritisation when geographical context is considered.

In this study, we use life cycle assessment (LCA) to compare the environmental impact of managing 1 tonne of post-consumer T-shirts collected in Sweden through reuse or recycling, in or outside of Europe, and incineration with energy recovery. Comparisons are enabled by expanding the functional unit with all functions generated by the case studies, and adding compensating processes in case studies lacking functions.

The results show that reuse has the lowest environmental impact, with a small difference between reuse in and outside of Europe. Also for recycling there is minimal difference in results in and outside Europe for all studied indicators , implying that the location of the recycling processes has limited impact on the environmental impact. Finally, for climate impact, there is no sizable difference between recycling and incineration.

These results, aligned with the waste hierarchy, will aid policy development for management of used textiles collected within Europe.

Integrating Durability in LCA for Textile and Apparel Products: Enhancing Quality Representation for Effective Communication

Agata Costanzo[1,2], **Marco Frey**[1], **Monia Niero**[1]

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The European Union is prioritizing the development of sustainable production and consumption regulations, with the apparel sector identified as a critical one due to its challenges, such as fast fashion. Herein, companies are required to reconstruct the life cycle of their products and evaluate their environmental impacts. The results of such assessments can drive production processes optimization and foster transparent communication with stakeholders, building trust and market competitiveness.

Therefore, capturing the quality and durability of products is essential for evaluating environmental impacts, mostly considering the fast fashion dynamics and the role of effective B2B and B2C communication. In this context, Life Cycle Assessment (LCA) plays a central role, especially in defining the functional unit and product lifetime. However, fully representing product quality and durability in the LCA modeling is challenging for apparel products, as these attributes are influenced by consumer-related variables such as usage patterns, perceived value, and fashion trends.

This study examines how product lifespan has been modeled in LCA studies of apparel products. A review of existing literature identified four main approaches: i) care cycles, ii) number of wears, iii) years of use, and iv) durability based on intrinsic product properties. Among these, durability-based methods, focusing on product characteristics such as material quality and design, appear underrepresented in academic literature, yet are adopted in policy-driven methodologies, such as the Apparel and Footwear Product Environmental Footprint Category Rules and the French Environmental Labeling scheme for textiles. These two frameworks adopt different approaches to modeling durability, raising questions about their impact on LCA results and environmental communication.

Session 1.18: LCA & Circularity to Improve Road Construction Env. Performance Part I

Time: Wednesday, 10/Sept/2025: 2:40pm - 4:10pm
Session Chair: Nicolás Héctor Carreño Gómez, VINCI Construction Shared Services GmbH, Germany
Session Chair: Davide Lo Presti, Universita degli studi di Palermo, Italy

Green Public Procurement: A Decision Support Tool for Quantifying Environmental Impacts of Asphalt Mixture Projects

Shaffie Ibrahim JUMA, David Hernando, Ben Moins, Wim Van den bergh

University of Antwerp - SuPAR, Belgium

This paper describes a tool developed to quantify and analyse the environmental impact of asphalt mixture projects. It is intended to support green public procurement practices by aiding road owners make informed decisions about the environmental impact of the asphalt mixtures they procure. The tool assesses 19 environmental impact categories which can be combined into a single score using the European union's recommended Product Environmental Footprint methodology. It covers raw material acquisition, asphalt mix production, material transportation, construction, deconstruction, and end-of-life phases. The tool allows users to select materials, energy sources, transportation modes, and operational machinery configurations. The energy sources for heating in the asphalt plant include natural gas, heavy fuel oil, propane, electricity, hydrogen, and combination of these options. Transportation modes and machinery options covered include truck transport, barge, ship, and trains with fuel sources such as bio diesel blends and electric options. Furthermore, users can adjust other variables such as binder type, recycled material content(recycled plastics and recycled concrete aggregates) and different types of additives to explore the impact of more sustainable choices. Lastly, a sensitivity analysis of specific mixes are presented to provide insights into the influence of each variable on the environmental impact categories, showcasing opportunities to reduce greenhouse emissions by allowing users to make sustainable asphalt production and construction choices.

Circularity in road construction: environmental benefits of asphalt and gravel recycling

Zhaniya Mukhamadiyeva[1], Rainer Zuest[2], Philip Buergisser[3], Roland Hischier[1]

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Construction of road infrastructure consumes vast amounts of primary materials, contributing to global warming, waste generation, and resource depletion. Currently, landfilling is the most common End-of-Life scenario for inert construction waste. However, increasing availability of and improvements in the recycling processes, as well as introduction of circular economy policies incentivize recycling and boost demand for secondary materials.

This study aims to quantify and compare the environmental performance of using conventional and recycled materials in road construction. In the first part, we focused on repairing 1'000 m2 of asphalt road with different shares (0%, 50%, 60%, and 80%) of reclaimed asphalt pavement (RAP) that is collected from a dismantled road section and recycled using different technologies. In the second part, we analyzed the impact of procuring one ton of secondary gravel (i.e. gravel that was excavated from the construction site, washed, and sent back), and compared it to the impact of acquiring the same amounts of natural gravel, or recycled gravel from crashing concrete. In the third (currently on-going) part, we will combine these two topics by assessing the environmental performance of constructing 1'000m2 of asphalt road, using the most

sustainable solutions for the asphalt as well as the underlying gravel.

So far, the obtained results show that recycling may significantly reduce the environmental load of road construction by lowering the use of environmentally-intensive materials like bitumen and natural gravel. Additionally, a simplified assessment of transport-related costs showed that sending excavated materials for recycling might be cheaper than their landfilling.

Acknowledgements. The study was financed by Bau- und Umweltschutzdirektion des Kantons Basel-Landschaft. The authors would like to thank Ammann Langenthal, Albin Borer AG, and Surer AG – for their support with inventory data for the various recycling processes.

Greening road construction: have we been doing it all wrong? A retrospective on key life cycle insights

Anne Cécile de Bortoli[1,2]

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LCA has been used for three decades to drive green and low-carbon practices in the road industry, resulting in hundreds of publications comparing the environmental impacts of various road construction techniques. These techniques primarily focus on: 1) low-impact materials: replacing virgin materials in pavement mixtures with industrial by-products, recycled materials, or bio-based alternatives; 2) energy efficiency practices: primarily lowering asphalt mixing temperatures, 3) optimized pavement designs: frequently comparing concrete and asphalt pavements.

However, many LCA rankings may be inaccurate. The first issue is the use of low-quality or incomplete inventories, such as those for bitumen (de Bortoli et al., 2024) or additives. Secondly, the choice of allocation methods to evaluate industrial by-products complicates LCA recommendations, as exemplified by "low-carbon concretes." Thirdly, comparisons between asphalt and concrete roads rely on different design models, leading to inconsistencies in LCA results. Asphalt pavements exhibit viscoelastic behavior, while concrete pavements have elastic behavior, requiring distinct physical models for their design. This behavioral difference particularly results in non-comparable discrepancies between the modeled and real-world lifespans of asphalt and concrete pavements, making LCA rankings unreliable when considering a well-defined functional unit that includes lifespan.

But do these limitations even matter? Global road construction, including maintenance and end-of-life stages, likely accounts for only a small percentage of the life-cycle environmental impacts of the road system. Most impacts come from vehicle fuel consumption, followed by vehicle amortization (e.g., de Bortoli and Agez, 2023). Consequently, the most critical factors in reducing the environmental impacts of roads are pavement surface condition and geometry—i.e., how roads are built and maintained to minimize vehicle fuel consumption and wear (de Bortoli et al., 2022).

While achieving sustainable net-zero requires both major and minor efforts from all stakeholders, keeping the above considerations in mind will be essential for prioritizing mitigation actions in road construction.

Data variability in EPDs of construction products

Bojana Petrovic, Mehrdad Ghorbani Mooselu, Hanne Lerche Raadal

Norwegian Institute for Sustainability Research (NORSUS)

The built environment is key to achieving carbon neutrality by 2050, with buildings accounting for 37% of global GHG emissions. Increasing the use of life cycle assessments (LCA) is essential for reducing emissions from construction products. In July 2023, Norway introduced climate regulations for new buildings, which requires an LCA of new construction products to be declared. The regulation drives Norwegian building sector to conduct LCAs for new buildings and enhance knowledge of environmental product declaration (EPD) for local products.

This study examines EPD variations for Norwegian crushed stone, focusing on emission differences across crushing stages and inconsistencies in declarations by product and producer. By examining 40 EPDs, the study highlights variations in declared emissions and reporting practices, which challenge comparability and decision-making. Disparities in reporting practices such as aggregating multiple crushing stages or introducing extra stages complicate emissions comparison. Additionally, deviations such as lower emissions reported in later stages question the reliability of data and transparency in reporting.

Data collection and classification involve extracting EPD data and comparing emissions by crushing stages in a standardized database. Benchmarking establishes reference emission ranges, aiding in identifying deviations. The study emphasizes standardized reporting through improved Product Category Rules (PCRs) to ensure comparability and informed decision-making. Recommendations include mandating cumulative emission reporting across stages, providing clear descriptions for each stage, and standardizing product categorization. Finally, a harmonized categorization of product types/qualities should be defined and used across all EPDs to make it possible to compare the environmental performance between similar products/qualities. Thus, the findings aim to advance the reliability and harmonization of EPDs ass critical tool for assessing the environmental impact of construction materials. Stricter standardized rules and requirements for performing EPDs will help to differentiate between variations due to methodological disparities and those due to real differences in performance of the products.

Towards Sustainable Road Construction: Benchmarking Carbon Emissions and Incorporating Environmental Performance Metrics in Road Construction Procurement

Nicolás Héctor Carreño Gómez[1], Pamela Haverkamp[2]

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The construction sector is widely recognized as the main contributors to pressing environmental impacts due to its high carbon emissions and contribution to the global energy demand. Considering this, it has become crucial to develop practical approaches to incentivize the reduction of carbon emissions and other environmental impacts. Scandinavian countries as well as the United States and the Netherlands have been successfully using Environmental Product Declarations (EPDs) of road construction materials, to compare materials from different producers and foster competition for more environmentally friendly alternatives in tenders. This has shown an increased interest in the optimization of materials towards low(er) carbon-intensive materials . In Germany, since 2022, various pilot initiatives have been launched to explore similar approaches. A working group within the German Road and Transportation Research Association (FGSV) has developed a guideline with strategies to incorporate environmental performance metrics into procurement processes. As part of this effort, benchmarks for the impact category Global Warming Potential (GWP) have been calculated for the materials asphalt and concrete using a cradle-to-delivery (A1 to A4) approach, with the intention to expand the scope of this work to include additional materials, life cycle modules, and impact categories in the future. This ongoing development aims to further integrate environmental sustainability into road construction practices and promote the use of environmentally responsible materials.

Session 1.19: Life Cycle Based Tools and Data Science Interactions Part I

Time: Wednesday, 10/Sept/2025: 4:30pm - 6:00pm
Session Chair: Alessandro Manzardo, University of Padova, Italy
Session Chair: Monia Niero, Sant'Anna School of Advanced Studies, Italy

onlineLCA: a bridge between expert and user friendly LCA

Julia Cilleruelo Palomero, Francois Le Rall, Andreas Ciroth

GreenDelta GmbH, Germany

Life Cycle Assessments have helped LCA practitioners see the environmental burdens of systems, products and services. A usual LCA study roughly takes a minimum of 3 months and it requires meticulous data collection and modelling, sensitivity analysis and expert considerations, which have been, until now, made by LCA practitioners.

The market nowadays requires more sustainability assessments, for many (or all) subproducts of a company, in specific formats, following specific standards. Regulations asking for these environmental statements have gone from being mandatory for only some sectors, e.g. construction products, to expanding to other sectors, e.g. automotive. Companies want to adapt, but might not have the resources to have an inhouse LCA practitioner, or it takes time to train someone to reach to that expertise level, or maybe they want to automatise their assessments and reporting.

Since 2.5 years, onlineLCA helps non-experts to access LCA models for their products, where they can change certain features in an easy-to-use interface, allowing to easily calculate and communicate new results. onlineLCA is a web-based product made by GreenDelta. It stores openLCA models in the background, which can be accessible by the web with a nice, customisable interface. Parametrised models made by LCA experts can then be accessed by non-LCA experts. End-users can see and change the model, run results, analyse hotspots, make comparisons between different products, and communicate this. It also allows to have user management and control, so that different parties in, or working with, a company can access and change the model in different ways, e.g. a user that can only run and analyse results, but not change the model vs a user that can change parameters in the model.

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

Unlocking the Potential of Life Cycle Data for Optimal Sustainable Systems Design via PULPO

Fabian Lechtenberg, Gonzalo Guillén Gosálbez

Institute for Chemical and Bioengineering, Department of Chemistry and Applied Biosciences, ETH Zürich, Switzerland

The increasing availability of life cycle data, spanning economic, environmental, and social dimensions, empowers practitioners to conduct more precise and nuanced life cycle assessments (LCA). In the pursuit of sustainable decision-making, evaluating diverse system configurations, including degrees of freedom such as raw material suppliers, processing technologies, and end-of-life treatments, has become increasingly important. Identifying the optimal configuration that aligns with decision-makers' values poses a significant challenge, as evaluating a multitude of scenarios is often impractical. Mathematical optimization offers an effective solution to this problem, as demonstrated in various studies.

To address the need for a practical way of conducting such assessments, we developed PULPO, a tool de-

signed to enable life cycle practitioners to seamlessly perform life cycle optimization (LCO) using available environmental life cycle inventory data. Building upon Brightway2 for data handling, PULPO supports inputs from manually crafted foreground inventories, but also background databases such as ecoinvent, and prospective databases generated through tools like premise. By enabling systems optimization based on these inputs, PULPO enhances the utilization of extensive data repositories, supporting more informed and effective sustainable decision-making.

PULPO has been successfully applied to multiple case studies, including the optimization of a prospective system integrating the electricity and chemical sectors via carbon capture and utilization. In this contribution, we outline computational aspects of PULPO, offer guidance on the system complexities that benefit most from optimization-based approaches, and explore the requirements for harmonizing economic and social life cycle data to be used with PULPO. By doing so, this work provides insights into the steps required to progress from environmental LCO to life cycle sustainability optimization (LCSO), laying the foundation for a more refined and efficient approach to sustainable systems design through optimization.

A Path to Sustainable Products: Tracking Carbon Intensity with on-line Digital LCA

Paulo Cesar de Campos Barbosa, Montserrat Motas Carbonell, Gilvan Anderson Gadioli Fischer, Ricardo Guasselli Torres, Cristina Neves Passos, Helbert Ronei Paiva Teixeira, Fabio dos Santos Liporace, Marcelo Cardoso Marques, Sidney Comandulli

Petrobras, Brazil

Petrobras has developed a digital model to conduct Life Cycle Assessments (LCAs) in its refineries, emphasizing agility in calculating the carbon intensity of products. The system has already been implemented in six refineries, which are currently undergoing a validation and improvement process, with plans for expansion in 2025 to encompass most of Petrobras' refining production. Preliminary results are already being assessed and used internally to improve our refining processes and develop products with reduced greenhouse gas emissions (GHG), contributing to the energy transition and a low-carbon economy.

The Digital LCA model uses real-time data from refinery management systems, including the refinery process Digital Twin and energy performance data. It also incorporates information from SIGEA® (Atmospheric Emissions Management System), the product movement database, and other complementary systems. The model adheres to ISO 14040 and ISO 14044, focusing on the environmental impact related to global warming potential.

The system calculates the carbon intensity of internal streams within each refinery process, assessing each process's contribution and the crude oil basket's influence. This data set allows for flexible and traceable carbon intensity calculations, aiding in the understanding and management of GHG emissions. Consequently, it facilitates the development of lower carbon-intensity products, meets customer demands, and provides essential data for sustainable product certification.

This paper will present the Digital LCA of RPBC (Presidente Bernardes Cubatão refinery), a complex Petrobras refinery. It will describe the experience of implementing this online carbon intensity calculation system, detailing some relevant aspects and benefits. It will also discuss how this information meets market demands for lower GHG emission products. We will highlight the R5 Diesel case, which is already produced in RPBC by processing mineral diesel combined with renewable content, such as vegetable oil.

Bridging the Gap: Developing a LCA methodology and tool for Industrial Services at Siemens

Amelie Fehm, Mariana Gaspar Martinez, Carina Echtler, Alexander Bayer

Siemens AG, Germany

With the increasing focus on sustainability, Life Cycle Assessment (LCA) has established itself as a critical tool for measuring environmental impacts. Traditionally applied to products, LCA for services has often been overlooked despite services accounting for a significant portion of Siemens' order intake and revenue. Siemens' commitment to sustainability is anchored in the DEGREE Framework, in which environmental impact transparency through LCAs and Environmental Product Declarations (EPDs) builds a cornerstone. However, current industry standards and regulations predominantly address products, creating a gap for industrial services, which lack applicable Product Category Rules (PCRs) and standards.

Recognizing this gap, Siemens has taken the initiative to develop a new LCA methodology and LCA calculation tool tailored specifically for services. This innovative approach mirrors the product LCA methodologies by categorizing Siemens' industrial service offerings into Relevant and Homogeneous Service Families, forming the foundation for defining functional units. This enables a comprehensive evaluation of environmental impacts throughout the entire service intervention.

A minimum viable product was built for on-site field services, which calculates the LCA for the entire service intervention based on five service steps, each incorporating necessary inputs such as electricity and transportation. In the EPD, the results for each service step are classified into one of three categories: off-site activities at Siemens, on-site activities at the customer, and travel and accommodation. This modular framework allows for seamless expansion to additional services within our portfolio, ensuring broad applicability and flexibility.

This new methodology and tool empower Siemens to efficiently perform LCAs and produce EPDs for services on a large scale. The application of the methodology and tool will be demonstrated through an example use case.

Applications of artificial intelligence algorithms and approaches in the life cycle sustainability assessment field: a topic modelling investigation based on large language models

Antonino Marvuglia, Simone Zorzan, Enrico Benetto

Luxembourg Institute of Science and Technology, Luxembourg

The pervasive and exponentially increasing diffusion of artificial intelligence (AI) in every research field has spurred a very large number of publications, rendering the task of keeping abreast of the most recent advancements and new research directions very challenging, even on a restricted topic area. In life cycle assessment (LCA) AI is used for tasks such as predicting outcomes, classifying data, filling data gaps, or extracting interpretable rules. In this perspective, recent text data mining and natural language processing technologies can also help undertaking objective and time-efficient literature analyses. For this reason, using large language models (LLMs) also to help in the compilation of systematic reviews, and to discover relevant 'topics' along with their temporal evolutions is now becoming increasingly popular.

We performed topic modelling on a corpus of 500+ documents published during the last decade, that dealt with applications of AI and machine learning techniques to life cycle sustainability assessment, including Safe and Sustainable by Design (SSbD) of new chemicals and materials. We used the popular transformer model BERTtopic, that creates context-sensitive embeddings for text documents, to perform advanced text mining. The corpus was extracted from both the scientific databases WoS and Scopus and then extended by adding a second set of 60+ technical reports retrieved from various sources (European Commission, OECD, JRC, Google Scholar, and others). We created a bespoke prompt to evaluate the use of a LLM to au-

tomatically sieve the corpus, according to our defined exclusion criteria.

Our research showed that, BERTopic allows to extract meaningful topics from a literature corpus, define topics' metrics (inter-topic distances, maps of hot topics, clustering of both topics and documents) and trace their evolution over time, confirming the potential of this approach.

Integrating LCA in the design process. A BIM based tool to quantify the environmental footprint of railway infrastructure projects

Francesca Reale[1], Carla Di Biccari[2], Christian Fontana[1], Mattia Mangia[2]

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The construction sector is responsible for significant GHG emissions and other environmental pressures, e.g. resource consumption. While the LCA is a recognized methodology to quantify the environmental impacts of construction products and buildings, its use for infrastructure is limited, also due to the infrastructure projects' complexity and, in turn, to the high effort needed to set the study (e.g. for data collection, inventory validation, modelling), especially when LCA expertise is external to the design team.

In the project "BIM4Rail-LCA – Development of LCA-BIM integrated solutions to design sustainable railway infrastructure" (2020-2023), funded by the Italian Ministry of Economic Development and implemented by Italferr (leader), Ecoinnovazione and University of Salento, a BIM-based tool (WebApp) for LCA of railway infrastructure projects was developed to integrate the design process, allowing environmental considerations since the early-design phase.

The development of the WebApp required firstly the development of LCI/LCA data for components used in railways infrastructures and secondly, the implementation of Property Sets related to elements in the BIM models and integrating information needed for the LCA (e.g. the material, the construction method).

The WebApp allows to work on BIM models in IFC-format. Once the IFC-model is uploaded, the WebApp scan it and visualize the LCI, using the granularity and nomenclature managed by the designers and reflecting the quantities resulting from the BIM elements' geometry. The WebApp automatizes the project data collection while fostering full understanding by the designers. Additionally, thanks to warning messages, potential discrepancies in project data affecting the LCA are detected.

The presentation will illustrate 1) how the LCA data were developed, from the collection of technical information components-related to the elaboration of such information, highlighting the maintenance-oriented approach 2) how WebApp was set, including the development of PropertySets upstream 3) how information is visualized both at input (LCI-inventory) and output (LCA-results) level.

Session 1.20: Evaluations of Circular and Low Carbon Plastic Value Chains towards sustainability Part I

Time: Wednesday, 10/Sept/2025: 4:30pm - 6:00pm
Session Chair: Tomas Ekvall, Tomas Ekvall Research, Review & Assessment (TERRA), Sweden
Session Chair: Christian Krüger, BASF, Germany

Net-zero chemical recycling routes for flexible polyurethane foams

Eleonora Bargiacchi, Luca Bosetti, Inès Lanfranconi-Schmid, Martin Pillich, André Bardow

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To address climate change and environmental pollution, the plastics industry must transition from linear to circular production. Circular strategies for the plastics industry have mainly focused on biomass and CO2 as a feedstock. A crucial additional role is expected for recycling. However, current recycling rates and technologies are insufficient to achieve plastics with net-zero greenhouse gas (GHG) emissions. In particular, crosslinked polymers cannot be recycled yet. For these cases, chemical recycling is emerging as promising technology.

For polymers such as flexible polyurethane (PU) foams, chemical recycling can target a variety of chemicals ranging from its direct precursors, toluene diisocyanate (TDI) and polyol, to base chemicals. Among these options, the target for a future recycling process is still unknown.

This work evaluates chemical recycling routes for flexible PU foam to minimize environmental impacts and identify the technology mix that could allow a transition to net-zero GHG production. For this purpose, we employ two complementing methodologies: the environmental potential and the Technology Choice Model (TCM). First, the environmental potential of 12 ideal closed-loop recycling routes for flexible PU foam waste at an early stage is compared to a benchmark waste treatment (e.g., waste-to-energy). Then, the CO2-optimal technology mix for the waste treatment and consequent production of recycled foams is determined.

The results suggest that chemical recycling of flexible PU foam offers substantial environmental potential across all impact categories, particularly when recovering both its precursors. However, recycling PU foam to low-value monomers (e.g. toluene or syngas) only slightly reduces climate change impacts while negatively affecting other environmental impacts. Orchestrating recycling routes into a consistent value chain allows flexible PU foam with net-zero GHG emissions if both building blocks are recovered and low-carbon electricity is available. The present work thus demonstrates the integration of life-cycle assessments into the design of future value chains.

Life cycle greenhouse gas (GHG) emissions of waste plastic used in automobile production according to recycling methods

Jaeyeon Ahn, Wonjae Choi

Ewha womans university, Republic of Korea

The importance of carbon neutrality is increasingly emphasized. Particularly, as the demand for vehicles is rapidly rising worldwide, the automotive industry has emerged as a key target for reducing GHG emissions. This study aims to derive measures to reduce GHG emissions during the disposal and recycling processes of vehicles. To achieve this, it is necessary to reduce the GHG emissions of the components constituting vehicles. Plastic is a material that is increasingly being used worldwide. Especially in the automotive industry, there is a growing trend of utilizing plastic parts more extensively due to their lightweight nature and relatively low cost. However, the production, use, and disposal of plastic cause various environmental

problems. Currently, the main methods for plastic disposal are landfilling, incineration, and mechanical recycling. However, landfilling and incineration have limitations in reducing GHG emissions, and mechanical recycling is constrained in terms of the scope of recycling applications and quality improvement. Consequently, chemical recycling methods such as pyrolysis and depolymerization are gaining attention. In this study, the GHG emissions resulting from the recycling methods of two types of plastics, Polypropylene (PP) and Polyethylene (PE), primarily used in the automotive industry, were analyzed. To quantitatively compare environmental impacts, a life cycle assessment was conducted using the GREET program developed by the Argonne National Laboratory. In addition, a simulation of plastic pyrolysis was conducted using Aspen Plus. The analysis results were synthesized to compare the environmental impacts of each recycling method and derive measures to reduce GHG emissions considering each method's pros and cons.

Rethinking life cycle assessment with recycled polylactic acid - Harnessing Waste Streams as Feedstock for Biobased plastics Production

Maelenn Ravard[1], Ana Morao[2], Eleni Moutousidi[2]

[1]TotalEnergies Corbion, The Netherlands; [2]Corbion, The Netherlands

TotalEnergies Corbion (TEC) produces Polylactic Acid (PLA), a biobased, compostable, and recyclable polymer, from sugarcane in Thailand. PLA, derived from biobased feedstock, has significantly lower carbon footprint compared to conventional polymers. The carbon in PLA, known as biogenic carbon, comes from atmospheric CO2 captured by sugarcane plants. At the end of its life, this carbon is released back into the atmosphere, maintaining a neutral carbon balance.

TEC further addresses the challenge of carbon emissions at the end of PLA's life by recycling post-industrial and closed-loop post-consumer PLA waste. Instead of incineration or composting, the PLA waste undergoes hydrolysis, breaking down the polymer into lactic acid. This recycled lactic acid is then repolymerized to produce recycled PLA, with the same quality as virgin PLA. Next to this, recycling PLA reduces the need for new agricultural feedstocks, minimizing impacts such as land use, eutrophication, and water consumption. Producing lactic acid from PLA via depolymerization also has a significantly lower environmental impact than producing it from sugar.

A key benefit of recycling PLA is the avoidance of biogenic CO2 emissions at the end of its life. The biogenic CO2, originally captured from the atmosphere, is stored longer in the product, enhancing temporary carbon storage and reducing atmospheric carbon. TotalEnergiesCorbion conducted a Life Cycle Assessment (LCA) of both virgin and recycled PLA, highlighting the significant contribution of biogenic carbon to global warming potential. Despite the lack of consensus on modeling biogenic CO2 in LCA, the approach followed demonstrates the benefits of biobased and recycled biobased polymers.

Life cycle assessment of a preindustrial chemical recycling process for chemical feedstock production

Darius Steegborn, Philip Biessey

Ruhr University Bochum, Germany

Plastics have become an indispensable part of today's world. With steadily increasing production and waste volumes, the global movement towards a circular economy requires plastics to be recycled in addition to waste prevention strategies. Existing recycling methods that are implemented in waste treatment systems are limited to sorted and clean waste fractions, while the remaining waste is mainly incinerated or landfilled. To keep these waste fractions in the cycle, chemical recycling methods are being developed to complement the existing recycling methods. One such process type is liquefaction, that can handle mixed, impure and complex plastics wastes by cracking polymers to produce oils, waxes and gases that can be

used to replace fossil feedstocks in the chemical industry. To determine the environmental impact of these energy-intensive processes and compare them with the state-of-the-art incineration, and in particular with the environmental impact of the substituted fossil products, life cycle assessments need to be carried out. Existing life cycle assessment studies are limited in accuracy and partly omit aspects such as pre-treatment of the feedstock or upgrading of the recovered products, before they can be reintegrated to the chemical industry, due to the early stage of development of the recycling processes.

In this submission we present a life cycle assessment study of a pre-industrial continuous liquefaction plant, with a technology readiness level of 8. To complement data for the product upgrading, we developed a process simulation sequence to calculate inventory data for product purification and separation. With two major scopes, we evaluate the environmental impact of the recycling process and compare them to #1 the state of the art incineration of different waste streams and #2 and the fossil based route of the derived products. To consider the developing energy supply, we also assess environmental impacts based on expected future energy mixes.

Including impacts from littering in LCA: a case study of to-go cups

Christina Galafton[1], Vaibhav Budhiraja[2], Sarah Stevens[3], Branka Mušič[4], Daniel Maga[1]

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The durability of plastics is one of the key characteristics for many product applications. However, when littered to the environment, this longevity turns into a threat to ecosystems, which is usually not considered in conventional life cycle impact assessment methods. We conducted a cradle-to-grave LCA of to-go plastic cups made of Polypropylene (PP) and Polylactic acid (PLA) for two End-of-Life scenarios: incineration and recycling. We include impacts related to (i) the use phase concerning human toxicity of leachates based on a toxicity experiment and (ii) the littering of these cups based on an assumed littering rate and degradation rates obtained during a weathering simulation.

Overall, the conventionally assessed environmental impacts of the PP cup are lower than those of the PLA cup. Fostered by the lower weight of the PP cup and its faster degradation in the weathering experiment, plastic pollution is also lower for the PP cup. However, the PLA cup showed lower scores in the toxicity experiment.

Concluding, despite being made of a biobased material, the PLA cup shows no environmental advantages compared to the PP cup. The better performance of the PLA cups regarding use phase human toxicity is outweighed by the scores in the other impact categories.

The case study stressed the importance of using product-specific degradation data when assessing plastic pollution impacts, as the experimental data varied significantly from the one identified in a literature review. Besides, the choice of a weighting factor for plastic pollution also influenced the results.

Evaluating the relative contribution of polymers and chemical additives in the environmental profile of plastic items.

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Plastic production and consumption are increasing globally, despite consistent concerns from the scientific community regarding their environmental impacts. A critical issue lies in plastics' ability to infiltrate environmental compartments, compounded by insufficient consideration of their complete environmental profiles. Life cycle assessment (LCA) has highlighted both the benefits of plastics compared to alternatives and the gaps in current models, which fail to account for the physical effects of plastic particles and chemical impacts from additives of plastics reaching the natural environment.

This research investigates the environmental hazards of everyday plastic products, focusing on the relative contributions of polymers and additives. Using data from plastic litter inventories, 22 commonly found plastic items from two large sectors —food packaging and fishing gear— were analyzed. The polymer and additive contents were identified and translated into environmental damage indicators using two environmental fate scenarios. Complete life cycle profiles for different end-of-life options were also assessed.

Findings reveal that microplastic emissions from polymers often contribute the most significant environmental impact, especially for food packaging items, where additive regulation is more stringent. On the other hand, additives in fishing gear seem to pose a greater impact but still less than polymers. The potential impacts from plastic leakage are particularly pronounced for an item leaked in the environment, hence with a 100% leakage rate, dominating total life cycle impacts. Yet, these results are constrained by limited data on additive content, representing only a fraction of the chemicals present in plastic products.

This study underscores the urgent need for improved policies regulating chemicals in plastics. Enhanced transparency from industries regarding additive concentrations is essential to accurately assess and mitigate the overall environmental impact of plastic products. The findings offer valuable insights for eco-design and highlight the necessity for developing specific impact indicators for plastic-related chemicals.

Session 1.21: LCM for the Biobased Economy: Innovative Methods and Practices Part II

Time: Wednesday, 10/Sept/2025: 4:30pm - 6:00pm
Session Chair: Thomas Schaubroeck, Luxembourg Institute of Science and Technology, Luxembourg
Session Chair: Tamara Coello García, Cesefor, Spain

A Methodological Approach to Monitor Outcomes of Sustainability Certification Schemes and Labels in the Bio-based Sector

Maulidia Khairani[1], Li Shen[1], Matthias Grill[2], Felipe Coelho Costa[3], Julian Piaskowy[3], Mikhail Rai[4], Ana Gabriela López Camey de Schrader[4], Matilde Festi[5], Elena Rocco[5], Costanza Rossi[6], Sergio Ugarte[6], Birka Wicke[7], Martin Junginger[1]

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Certification Schemes and Labels (CSLs) are essential instruments for promoting sustainable production and consumption practices while ensuring the sustainability of bio-based products across borders. Despite their potential, the effects and robustness of CSLs of bio-based products remain under-examined, particularly in light of their proliferation and varying levels of robustness in the market [1], leaving a critical gap in sustainable governance. Current monitoring frameworks, such as FAO Sustainability Assessment in Food and Agriculture (SAFA) and WWF Certification Assessment Tool (CAT), primarily assess CSLs based on their sustainability criteria and governance system but rarely address the actual contributions of CSLs to tangible sustainability outcomes.

This study seeks to develop a monitoring framework for evaluating the outcomes of CSLs and their contribution to sustainability objectives, with a specific focus on bio-based products outside the energy and food sectors. This study offers a novel contribution by establishing a harmonised, evidence-based approach to evaluate CSL progress across diverse bio-based value chains aligned with EU Bioeconomy targets. By advancing a standardised and rigorous methodology, this study paves the way for more transparent, reliable, and actionable assessments of CSL impacts. This approach not only addresses critical gaps in CSL evaluation but also supports continuous improvement among CSL owners, informed policymaking, and academic discussions on impact measurement.

The feasibility of the proposed monitoring system is being tested with nine CSLs encompassing diverse focuses and scopes (e.g., FSC, EU Ecolabel). Preliminary findings highlight current practices, evaluate the framework's feasibility, and demonstrate its potential to effectively measure impacts. At the LCM 2025 conference, we will present key results, including: (1) theoretical perspectives on CSL impacts, (2) a validated monitoring framework, and (3) policy recommendations for integrating these findings into regulatory and governance frameworks.

ALIGNED: A field-tested framework for the LCA of bio-based products

Massimo Pizzol[1], Agneta Ghose[1], Søren Løkke[1], Kíra Lancz[1], Mathias Gustavsen[1], Marcos Djun Barbosa Watanabe[2], Nariê Rinke Dias de Souza[2], Francesco Cherubini[2], Damien Arbault[3], Lorie Hamelin[3], Maxim Tschulkow[4], Jurjen Spekreijse[5], Patrick Reumerman[5]

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We intend to present the final results of the ALIGNED project (Horizon Europe). In particular the insights from applying on six case studies a scientific framework for the life cycle assessment of bio-based products. The framework was initially put together after 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) into a coherent set of 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.

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 characterization 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.

In practice the framework 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 framework was then tested in six different case studies, each of them with industrial partners and real-world situations, and covering five different sectors: woodworking, construction, pulp and ppaer, textiles, and chemicals.

The presentation will describe the insights obtained from such field-testing and the modifications and improvements done to the framework to make it more relevant, applicable, and scientifically sound. The presentation will also provide an overview and map for understanding and navigating the material associated with the framework and how to access and use it.

Advancing the Residue-Based Bioeconomy: Life Cycle Assessment of Emerging Feedstock-Technology Combinations

Vanessa Zeller, Almut Güldemund

TU Darmstadt, Germany

The residue-based bioeconomy, utilizing agro-industrial by-products and biowaste to produce biobased products, is promoted as a sustainable and value-creating alternative to current economic models. However, significant challenges hinder its large-scale implementation, and environmental sustainability remains unproven. In Germany, an innovation area has been active for five years, focusing on developing novel feedstock-technology-product combinations in research, development, and innovation (RDI) projects while assessing their environmental performance using life cycle assessment (LCA).

This initiative emphasizes creating an LCA framework to cooperate with RDI projects, standardize data collection, ensure methodological consistency across technologies, and define key performance indicators (KPIs). Special attention is given to incorporating residue use impacts and addressing technological progress through systematic upscaling from laboratory and pilot scales.

The LCA results show findings from 12 case studies that utilize by-products from the food industry, urban biowaste, and CO_2 from different point sources as feedstock. Conversion pathways include fermentation,

extraction, pyrolysis, synthesis, and insect farming, targeting high-value products in sectors such as food, feed, and chemicals. These emerging combinations are currently energy- and resource-intensive due to low technological maturity and long value chains. Nevertheless, early-stage upscaling demonstrates significant potential, with environmental impacts reduced by up to 90%. While residue use has a minor environmental contribution compared to process impacts at early stages, its relative importance increases post-upscaling. For categories such as land use, prospective LCA results suggest that certain pathways offer advantages over conventional approaches at the early fab stage.

In conclusion, incorporating feedstock considerations and technology maturity into LCA is critical for the assessment of bioeconomy RDI. Further advancements are necessary to improve environmental sustainability and ensure competitiveness with established technologies.

Is sustainability assessment fundamentally biased towards fossil-based materials?

Stuart Walker, Rachael Rothman, Maryam Hoseini

University of Sheffield, United Kingdom

LCA should allow the bias-free comparison of existing and new materials to understand and quantify sustainable choices. We will present findings from an interdisciplinary research project, a stakeholder engagement exercise and a detailed review of LCA standards, all of which suggest this is not the case.

We interviewed and collected experience from over 40 designers and manufacturers of bio-based and biodegradable materials. 95% of interviewees recognised the value of LCA for comparison, but 67% felt that LCA standards showed bias towards fossil materials. We studied this bias and suggest three areas in which sustainability assessment, and in particular LCA, inherently favours fossil-based materials.

Incomparability: Differences in assumptions, scope and attribution often lead to incomparability between fossil and bio-based or biodegradable materials. Standards should ensure comparability but even when fully adopted, we observed significant differences. 83% of our respondents believed that LCA regulation is currently unsatisfactory.

Implicit bias: Common impact categories and assessment methods were developed during fossil-based material incumbency, meaning categories in which bio-based or biodegradable materials perform well, for example microplastics, are often not included in established methods. Fossil materials are able to show their advantages whereas bio-based and biodegradable materials are not.

End-of-life treatment: Modelling compostability in LCA typically relies on generic data, which often requires manual adjustments. Most models do not include emission to soil and water, and often only include greenhouse gas impact categories, leading to inconsistency and implicit bias.

To address these problems, we suggest it may be necessary to reframe comparative LCA and develop a bias-free methodology to allow comparison between fossil materials and bio-based or biodegradable materials. We suggest a new set of impact categories, and specific guidance on the comparison of fossil and bio-based or biodegradable materials. We will present our proposals.

Time-explicit Climate Change Impact Assessment using the ALIGNED methodological framework

Damien Arbault, Lorie Hamelin

Toulouse Biotechnology Institute, CNRS, INRAE, INSA, Toulouse, France

Assessing the climate impacts of biogenic CO2 emissions is complex. Carbon uptake during biomass growth temporarily stores carbon, slowing the pace of global warming and related damages to slowly-adapting biodiversity and societies. In contrast, emissions occurring after this storage period have long-term impacts such as repeated extreme weather events and sea-level rise, similar to fossil-based emisisons. Thus, considering the temporal profile of greenhouse gas (GHG) emissions throughout a product's lifecycle is critical.

While climate scientists have highlighted the limitations of using static metrics like GWP100 (Global Warming Potential over 100 years), alternatives remain underutilized outside the scientific community. With growing interest in the bioeconomy, institutions and businesses are revisiting GHG accounting standards to fairly assess bio-based industries.

The EU Horizon-funded ALIGNED project addresses this gap by aligning private sector practices with scientific advancements in Life-Cycle Assessment (LCA). ALIGNED focuses on bio-based sectors, offering an open framework with guidelines, tutorials, and tools for practitioners. It includes ready-to-use calculators for time-explicit GHG methods and a dynamic model for biogenic carbon flows, preloaded with data for various tree species.

The framework has been tested with five industrial partners, showcasing real-world applications of time-explicit GHG accounting and its advantages for transitioning to low-fossil, bio-based industries. These examples highlight the added value and challenges of implementing advanced LCA methods, helping decision-makers anticipate future environmental standards.

This presentation will focus on one case study: the lifecycle of a bio-based insulating material, covering its production, use, and end-of-life stages.

Valorization of Carded Wool for Sustainable Composites in 3D Printing Applications

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The valorization of waste presents a critical challenge in promoting sustainability and circular economy principles. By integrating waste materials into production processes is possible to mitigate environmental impacts, drive innovation, and enhance resource efficiency. Low-quality sheep wool, often considered waste, has gained attention for its potential applications in the construction sector. Experimental uses include its role as discontinuous reinforcement in bricks and mortars, its incorporation into insulating panels for its thermoacoustic properties, and its integration into yarns or mats impregnated with polymer resins to enhance the mechanical performance of composite materials. However, the processing of wool encompassing stages such as washing, carding, and combing produces by-products like carded wool, which are frequently overlooked. These residues represent a valuable resource with significant potential for valorization, enabling more complete utilization of the raw material. This study explores an innovative application of carded wool waste in polylactic acid (PLA)-based composites, with a focus on 3D printing. The main

goal was to identify critical issues during the mixing of wool with PLA, in order to evaluate the composite's reliability and compatibility, as discussed in the literature. This initial optimization phase aims to develop a filament that will subsequently be tested for mechanical performance and environmental impact. The latter will be assessed using the Life Cycle Assessment (LCA) methodology, comparing results with filaments reinforced with other natural fibers already on the market. Fully valorizing this resource not only broadens its applications but also supports the development of sustainable and high-performance materials, delivering environmental benefits throughout their life cycle.

Considerations on the Role of Interregional Collaboration in Bio-Derived Resources Implementation: A Case Study of Cellulose Nanofiber Technology

Kayoko Shironitta[1], Yuko Oshita[2], Shunichi Hienuki[3], Yuichiro Kanematsu[2], Yasunori Kikuchi[2]

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Achieving a carbon-neutral society necessitates the adoption of innovative technologies and materials. However, despite their recognized utility, the high costs associated with production and implementation often hinder their widespread adoption. One such material, cellulose nanofiber (CNF), is plant-derived material and has a wide range of potential applications due to their unique properties. For example, its high strength allows it to be a promising alternative to carbon fiber as a high-performance resin reinforcement material. CNF is expected to play an important role in reducing dependence on petroleum-derived plastics and contribute to carbon neutrality. Moreover, CNF offers significant potential for domestic production in Japan, leveraging locally available raw materials such as wood and pulp, promoting domestic supply chains. Since CNF manufacturers and raw material producers are not always located in the same region, fostering collaboration between these regions can strengthen resource utilization and enhance the socioeconomic benefits of CNF implementation, which may help bridge the gap between innovation and practical implementation.

This study aims to assess the socioeconomic effects of CNF production by considering the geographic distribution of raw material production and the potential for interregional collaboration. Using municipal-level input-output (IO) tables, we evaluate the value-added ripple effects of CNF production and identify candidate sites for its implementation. By examining regions specializing in pulp production and their raw material sources, we emphasize the importance of fostering interregional partnerships to enhance economic benefits. Collaborative networks that link wood and pulp production regions with CNF manufacturing sites could enhance the overall effects of CNF implementation.

This research provides actionable insights for policymakers by presenting specific scenarios for considering CNF production locations and interregional networks. These results support strategic decision-making for stakeholders aiming to implement advanced materials like CNF into society while fostering sustainable economic development and contributing to carbon neutrality.

Life Cycle Assessment of Bio-Based Global Value Chains: A Case Study of a novel Bagasse-Based Polyurethane Foam Between Australia and Germany

Can Soenmez[1], Sebastian Spierling[1], Leonie Barner[2], Hans-Josef Endres[1]

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In a world with a growing material demand, climate change stands as one of humanity's greatest challenges, largely due to the increasing concentration of greenhouse gas (GHG) emissions from key sectors such as energy, transport, industry and buildings. These sectors are predominantly based on finite fossil resources, contributing to the severe consequences of climate change for ecosystems and human societies, and highlighting the urgent need for significant changes. A promising, renewable alternative is the transition to a biomass-based economy, or bioeconomy, which is gaining momentum under government-backed strategies and regulatory frameworks. Although biomass is produced in many regions, its availability, production efficiency and potential land-use conflicts vary, highlighting the need for coordinated global efforts beyond national borders rather than the prevailing national approaches. To ensure the sustainability of such a transnational bioeconomy, comprehensive assessments of bio-based global value chains (GVCs) are crucial to avoid burden shifting and exploitation.

This research examines the environmental dimension of a bio-based GVC through a Life Cycle Assessment (LCA) case study of a novel polyurethane foam produced from bagasse, an abundant second-generation biomass-feedstock in Australia, with the foam manufactured in Germany.

The LCA assesses the potential environmental impacts of bagasse-based foam and provides insights into how the impacts are distributed across individual processes within the value chain and the relevance of the geographical context of these processes. The study identifies critical factors for the sustainability assessment of bio-based GVCs.

This research serves as an initial building block in the development of a comprehensive framework for assessing sustainability in all its dimensions in the context of a transnational bioeconomy. Such a framework can be essential in guiding the design and implementation of sustainable bioeconomic practices, and in aligning and promoting international efforts to transition away from fossil resources towards a more resilient and sustainable global economy.

Sustainability Challenges in Pharmaceutical Packaging: A Life Cycle Analysis Approach

Samara Costa[1], Hector Nunes[1], Beatriz Sampaio[1], Tânia Simões[2], Bruno Silva[1], Cátia Zoraida[1], Catarina Basto-Silva[1]

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Pharmaceutical packaging represented approximately USD 133 billion, in 2023, and it is projected to exceed USD 285 billion by 2032, reflecting a compound annual growth rate of 9%. Pharmaceutical packaging typically included paper, plastics, glass, or aluminum foil. In the case of plastic packaging, one strategy to reduce environmental impact is the use of biomaterials or the promotion of recycling. In this context, this study aims to evaluate and compare the environmental performance of pharmaceutical packages made from conventional plastic versus a novel compound developed through a Portuguese research project, incorporating bio-based polyethylene (Bio-PE) and mussel shell. The environmental performance was assessed using the Life Cycle Assessment (LCA) methodology, following ISO 14040:14044 standards. The study adopts a "cradle-to-gate" approach, with the declared unit defined as the production of one pharmaceutical package. The life cycle inventory considered mass allocation and an attributional approach, while the impact assessment method used was the Environmental Footprint. The results showed that the package produced with the developed compound had a higher environmental impact than the package made from fossil-derived plastic. This can be attributed to the greater environmental impact of the agricultural phase

associated with the production of Bio-PE, which surpasses the impact of the fossil-derived polymer and also the long distances of associated transport. However, the use of natural waste materials, as mussel shell, appears to improve the environmental performance, reducing the environmental impact of producing one pharmaceutical package. In conclusion, while plastic materials in pharmaceutical packaging were identified as the primary drivers of environmental impacts, bio-based materials do not always represent the best environmental option.

Session 1.22: LCM implementation in SMEs

Time: Wednesday, 10/Sept/2025: 4:30pm - 6:00pm
Session Chair: Yahong Dong, Macau University of Science and Technology, Macau S.A.R. (China)
Session Chair: Mark Goedkoop, Product-ecology, The Netherlands

AI-enabled tool providing eco-design principles to manufacturing SMEs

Sebastien Zinck[1], Antreas Afantitis[2], Olivier Parisot[1], Ankit Arora[1], Duan Hua[1], Michael Saidani[1]

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Eco-design emerged in the late 90s, and while methods have evolved, adoption across manufacturing industries remains limited despite its potential to address 80% of a product's environmental impact since the design phase. Effective eco-design increases product circularity and minimizes life cycle environmental impacts, including climate change. EU policies like the Eco-design of Sustainable Products Regulation (ESPR), Carbon Neutrality by 2050, and European Sovereignty emphasize the importance of eco-designed products. However, while existing LCA tools enable environmental impact quantifications, tools providing eco-design guidance are currently lacking.

Developed via a Eurostars funding, the ECODEV tool is an innovative eco-design Software as a Service (SaaS) which provides product development teams – especially within manufacturing SMEs – with sector-specific, up-to-date, and actionable eco-design principles to support the creation of circular and sustainable products. ECODEV SaaS relies on AI-driven text mining and decision tree models, ensuring a comprehensive set of eco-design principles are considered and assigned to relevant product development actors. It will complement LCA tools by providing eco-design principles since the design phase. Moreover, in line with the Product Environmental Footprint (PEF) methods, a dedicated module will allow to collect data along product development to facilitate eventual LCA calculations and Environmental Product Declarations (EPDs) publication. The first version ECODEV SaaS is customized for the furniture sector, where most companies are SMEs: it will support the latter to comply with ESPR, fulfil the eco-design criteria of market-driven eco-labels and even eco-innovate.

Energy recovery from winery wastewater by aqueous phase reforming: A dual approach integrating environmental and economic prospectives

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An urgent increase in renewable energy demand is necessary to achieve net-zero CO2 emissions by 2050, as targeted by COP28, to prevent irreversible climate effects. Additionally, only 50% of the wastewater generated is correctly treated globally. Integrating renewable energy production technologies with effective wastewater management offers dual benefits, enhancing environmental sustainability. In this context, this study explores aqueous phase reforming (APR) for energy recovery and simultaneous chemical oxygen demand (COD) abatement in winery wastewater, assessing its environmental and economic implications. Winery wastewaters are characterized by high COD (300-300,000 mg/L), with ethanol being the predominant organic compound. Small alcohols, like ethanol, demonstrate high APR performance due to their high conversion rates and hydrogen yields. APR is a mild thermo-catalytic process that converts liquid oxygenated hydrocarbons into a H2-rich gas using a heterogeneous catalyst. The life cycle assessment (LCA) methodology was used to analyze the environmental impacts of the technology, and a techno-economic analysis

(TEA) using the Towler methodology assessed energy integration and profitability along the entire process chain. A plant capacity of 2500 L/h was modeled in Aspen Plus, considering two end-of-life scenarios: (i) combustion of the APR-generated gas mixture to produce electricity and heat, enabling surplus electricity commercialization, and (ii) hydrogen purification and selling. Preliminary LCA results suggest a threefold reduction in global warming potential (GWP), especially in the second scenario, when compared to established hydrogen production technologies. Moreover, TEA findings suggest that the first scenario offers lower overall production costs, with electricity prices aligning with national rates in Italy, while hydrogen prices, although higher than traditional steam reforming, are comparable to electrolysis costs. In both scenario energy self-sufficiency was achieved comprehensively thanks to heat integration. These outcomes highlight the dual role of APR in advancing renewable energy solutions through winery wastewater management, offering opportunities for further optimization and applications.

Proposal of a Maturity Model for Circular Bioeconomy (M2BEC) in small and medium-sized companies

Yovana M.B. Saavedra[1,2], Daiane Vitória da Silva[2,3], Carla Rodrigues[4], Fausto Freire[4], Diogo Aparecido Lopes Silva[2,3]

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Circular Bioeconomy (CBE) evolves business models developing high-value-added products based on bioresources use, the recovery of bio-based waste, and the cascaded use of materials. This contributes to changing the current linear business as usual to a circular and more sustainable production and consumption. However, Small and Medium Enterprises (SMEs) face challenges in transitioning to this direction and evaluating their maturity in relation to CBE implementation is crucial. In this sense, the aim of this paper is to present a proposal of a maturity model for circular bioeconomy (M2BEC) in SMEs. The maturity model was developed in four phases: i) the systematic literature review (SLR) to identify the main characteristics and business practices of CBE in SMEs. ii) version 1.0 based on the findings from the SLR. iii) pre-evaluation by two experts: the model was pre-evaluated by two specialists in maturity model development, CBE, and circular business models. Based on the feedback, a revised version, M2BEC 1.1, was created. iv) case studies and validation by experts to obtain the final version of M2BEC. The partial results present the M2BEC which is composed of four archetypes: 1. Optimising resource efficiency and use, 2. Innovation towards bio- and renewable resources, 3. Establishing biorefineries and resources exchange and 4. Service- and result- oriented value offers. The M2BEC includes six levels: Level 1-None. Level 2-Basic. Level 3. Explorative. Level 4. Systematic, Level 5.Integrative and Level 6. Regenerative. Additionally, the M2BEC includes support elements to help SMEs to improve their profile and advance to the next maturity level (based on a set of practices and indicators to be managed). In the next phase, the model will be evaluated by another set of specialists and at the same time perform some case studies in SMEs to obtain the final version.

Carbon Pricing in Canteens: Driving Change or Just Numbers?

Matthias Stucki, Dimitri Chryssolouris, Annette Jenny

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Food consumption is a major driver of environmental impacts in everyday behaviour. In partnership with two hospital canteens, the Zurich University of Applied Sciences (ZHAW) and the City of Zurich, we evaluated the potential of incorporating moderate carbon pricing into hospital meal choices as a measure to reduce food-related life-cycle greenhouse gas (GHG) emissions and other environmental impacts. For a total of 163 meals served in two hospital canteens over a reference period of 6 weeks, we quantified life-cycle GHG

emissions based on IPCC 2021 and total environmental impacts based on the Ecological Scarcity Method.

The same meals were served during a 6-week test period in which meal prices were adjusted based on life-cycle GHG emissions (carbon pricing). The price adjustment was based on the Menu Sustainability Index (MNI) developed by the ZHAW. Menu prices consisted of a constant (CHF 4) plus an amount based on CO2-eq per kg, ranging from CHF 7 to CHF 13, adjusted according to greenhouse gas emissions. Consumer acceptance of the adjusted prices was assessed through a guest survey.

Finally, we compared meal sales to determine whether carbon pricing induces behavioural change and to quantify the overall emissions reduction from implementing carbon pricing in hospital canteens.

Developing Practical LCA Methodologies for Emerging Technologies: Challenges and Approaches

Katsuyuki Nakano[1], Ichiro Daigo[2], Yasunori Kikuchi[2]

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Life Cycle Assessment (LCA) for emerging technologies presents unique challenges, including scale-up, defining functional units, and addressing future scenarios. This study aims to develop a structured LCA framework tailored to emerging technologies, incorporating future scenarios, TRL, and the application of technology.

To identify and refine existing methodologies, LCA studies for emerging technologies were retrieved using the Web of Science, and the most recent 100 cases were analyzed. The analysis focused on the goal of the LCA, Technology Readiness Level (TRL), functional unit, system boundary, and foreground/background data.

The analysis revealed two distinct purposes for conducting LCA. The first is social implementation-oriented LCA, which evaluates a technology's potential environmental performance, assuming that technical challenges have been resolved, utilizing future-oriented process data, such as scaled-up scenarios. The second is problem-identification LCA, which assesses current environmental performance using existing data to identify development-stage issues. Clear communication of assumptions is essential. For social implementation-oriented LCA, it is necessary to explicitly specify the technical challenges assumed to be resolved. For problem-identification LCA, assessments should clarify whether identified impacts can be mitigated before mass production.

Emerging technologies evaluated in the 100 studies could be categorized into three types: process improvement, function enhancement, and new function provision, each requiring tailored approaches to define functional units and system boundaries.

For background data, using a future-oriented database aligned with social implementation is ideal but challenging due to the expertise required to construct such databases. A practical approach, used in the surveyed LCA studies, is to apply future-oriented data selectively to key processes, such as electricity. Some cases assumed renewable energy exclusively for emerging technology, risking biased performance assessments. Modifications to background data must be applied consistently across comparative systems to ensure consistency.

Development of a Versatile Framework for Circular Economy Strategies for Plastic Products in SMEs

Meret Jürgens, Marina Mudersbach, Hans-Josef Endres

Institute for Plastics and Circular Economy, Leibniz Universität Hannover, Germany

Plastics are of key importance for numerous technical applications due to their functional properties and cost efficiency. However, their production and disposal pose a major environmental problem, as a significant proportion is dependent on fossil raw materials and recycling rates are inadequate. The transition to a circular economy (CE) is crucial to address these problems. This is also recognized by the European Commission in their Circular Economy Action Plans. SMEs in particular struggle to implement CE strategies. A detailed framework is developed that illustrates CE strategies in the plastics industry, focussing on the practical implementation in the product life cycle and the actual contribution of the strategies to a CE. Based on CE criteria, the strategies are sorted into different categories: circular economy, circular interaction, sustainable CO2 use and linear economy. Strategies such as the use of post-industrial recyclates and the use of biobased materials offer advantages but are not sufficient on their own to close material cycles. On the other hand, closed-loop recycling and the reuse of products that require customised collection systems may contribute to truly closed material cycles that can be even more sustainable. The framework serves as a comprehensive tool for discussing and implementing CE strategies for products by companies and promotes the transition to a sustainable plastics economy. Its practical application in SMEs in particular is discussed.

The analysis of the effects of modernization of the energy system in a food enterprise, carried out to reduce the impact on the environment

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The use of energy obtained from the energy mix in a country such as Poland, which is mainly based on coal, has a significant negative impact on the environment. One solution to this problem is the implementation of individual industrial renewable energy installations that produce energy for the needs of specific companies. This text refers to the case of using such an installation in a food industry company. The article analyses the impact of implementing a photovoltaic installation on the harmfulness of the mass packaging process of bottles, using foil with 50% recyclate, conducted in the company. The research was carried out using SimaPro 9.6 software, which contains the Ecoinvent 3.0 database, and the IMPACT World+ Endpoint V1.02 and IPCC 2021 GWP V1.01 methods were used to determine the environmental impacts, which allowed for detailed identification of key parameters influencing the size of the carbon footprint and other impact categories. The conducted analysis comparing the potential impact on the environment of the process before and after the modernization of the company showed that the process of mass packaging of bottles in the company after the introduction of the photovoltaic installation potentially generates about 90% less harmfulness and about 86% smaller carbon footprint. Producing energy from its own source allows the company to reduce energy costs and at the same time reduce dependence on rising electricity prices, which result from the increasing costs of raw materials such as coal or gas. The conducted environmental impact assessment proved that the modernization of energy systems using renewable energy sources is an effective solution that combines ecological and economic benefits, thus responding to the growing requirements in the field of environmental protection and sustainable development.

Session 1.23: Thermochemical Waste Management: Status & Outlook

Time: Wednesday, 10/Sept/2025: 4:30pm - 6:00pm
Session Chair: Filomena Ardolino, University of Campania "Luigi Vanvitelli", Italy
Session Chair: Umberto Arena, University of Campania Luigi Vanvitelli, Italy

Life Cyle Sustainability assessment of a novel chemical recycling technology for conversion of waste to olefins

Massimiliano Materazzi, Aurora Cavaliere, Andrea Paulillo, Paola Lettieri

University College London, United Kingdom

Olefins serve as fundamental building blocks for numerous chemicals and materials. However, conventional methods of olefin production rely heavily on fossil fuels, thus raising significant environmental concerns. Advanced thermochemical technologies present a promising sustainable alternative by harnessing renewable biomass largely present in waste, together with other non-recyclable fossil fractions, to generate syngas, which can then be converted into olefins via commercially proven Methanol-to-Olefins (MTO) processes.

This project focuses on a novel olefin synthesis process specifically tailored for operating with CO2-rich feedstock and medium scale plants (100,000 tons/year), as in the case of syngas obtained from the gasification of waste. In particular, the sorption-enhanced olefin synthesis (SEOS) technology helps us to overcome thermodynamic limitations associated with methanol formation and subsequent dehydration, thus improving yields and selectivity towards light olefins, while reducing energy consumption and CO2 by-products.

A sophisticated set of models has been developed using Aspen Plus to simulate the performance of the fully integrated waste-to-olefins system, as well as to produce the mass and energy balance of a first commercial plant. Experimental data (including data from ABSL plant) have been directly used to inform the product distribution of waste-to-syngas intermediate gas, and direct syngas-to-olefins in the presence or absence of water removal steps. An energetic optimization and a sensitivity analysis on different parameters were done to probe and increase the overall efficiency of the plant.

Finally, the optimised mass and energy balances has been used to perform a compressive Life Cycle Assessment (LCA) analysis to unveil the environmental performance but also the bottlenecks of the process, comparing with conventional olefin synthesis processes, analysing different impact categories, such as climate change, resource use, energy carriers, eutrophication freshwater, etc. using a cradle-to-gate approach.

Integrating Process simulation and Life Cycle Assessment: A Case study on Polyethylene Gasification for Hydrogen, Hydrocarbons, and Methanol Production

Alessandro Salvi, Andrea Locaspi, Matteo Pelucchi, Giovanni Dotelli

Politecnico di Milano, Italy

The process industry faces increasing pressure to adopt sustainable practices while overcoming challenges such as narrow profit margins and a conservative approach to innovation. One critical barrier is the difficulty in quantifying environmental impacts during the early stages of process design, often due to limited primary data and a lack of comprehensive life cycle assessment (LCA) frameworks tailored to industry-specific needs.

This study presents an integrated workflow for evaluating the feasibility and envi-ronmental performance of polyethylene (PE) gasification. It combines mechanistic chemical simulations, process modeling, and environmental assessment to address these challenges effectively.

The starting point was literature plant schemes optimized in the proposed configura-tions. Then, a detailed reactor gasification model was carried out with OpenSMOKE++. Indeed, OpenSMOKE++ was used to predict gasification product distributions based on validated chemical kinetic models, while process simulation in Aspen Plus® was adopted to quantify the plant performance. Eventually, material and energy flows generated in Aspen Plus® were linked to the LCA software Bright-way 2.5 through a Python-based framework, enabling direct computation of envi-ronmental impacts.

The approach was applied to three scenarios targeting hydrogen, hydrocarbons via Fischer-Tropsch synthesis, and methanol production from waste PE, considering a functional unit of 1 ton of waste PE processed in Italy.

Comparative analysis with a Waste-to-Energy (WtE) plant showed that hydrocarbon and methanol production outperform WtE in terms of Global Warming Potential (GWP100) when heat and electricity recovery are considered. Potential improve-ments, such as renewable energy integration and advanced heat recovery, could fur-ther reduce the environmental footprint of gasification-based systems.

This work exemplifies the potential of integrating process simulation with advanced LCA tools to assess and optimize sustainable waste management technologies. By leveraging the flexibility of open-source LCA tools, the proposed framework pro-motes the development of environmentally conscious process design.

A life cycle management approach to assess environmental performance of a waste-to-hydrogen strategy

Umberto Arena[1], Francesco Parrillo[1], Simone Malvezzi[2], Lorenzo Privitera[2], Filomena Ardolino[1]

[1]University of Campania "Luigi Vanvitelli", Italy; [2]A2A Ambiente S.p.A – A2A Group

European policies increasingly promote strategies for producing secondary resources from waste (such as, recycled materials, energy, fuels, and chemicals) to achieve stringent sustainability goals. These interactions between the sectors of waste management, manufacturing, energy, and transportation are leading to new integrated systems, which require to be optimised from technical, economic and environmental point-of-views, following a life cycle management approach.

This study focused on a new Waste-to-Hydrogen (WtH2) strategy, where a waste combustion plant (WCP) is coupled with an electrolyser, by providing it "renewable" electricity to produce hydrogen, in turn utilised in a regional railway line. The investigation covered three WCPs, all operating in Italy, and managed by the same private company, interested to implement the so-designed WtH2 strategy in a close future. The aim was to quantify the environmental performance of the WtH2 systems, and to verify their compliance with the EU decarbonisation goal, which establishes a threshold of 3 tCO2eq for 1 tonne of H2 produced and

utilised.

A Life Cycle Assessment with a "separate share" approach was adopted, i.e. the multi-functional WtH2 systems were subdivided into single unit processes, to isolate only the parts of the system specifically working for the analysed function. A "product&tranportation" perspective was chosen, by considering "the regional railway transportation service for the kilometres travelled with 1 tonne of H2" as the functional unit. The alternative scenarios were those that utilise trains fuelled with diesel or hydrogen from steam reforming.

Results showed that the WtH2 systems have a clearly better overall environmental performance, with savings up to 42 tCO2,eq for each tonne of H2. The main contributions for each WCP were identified, by highlighting the effects on the results deriving from their different characteristics (in terms of treatment capacities, kinds of input waste, and recovered co-products) and providing useful information to the management company.

The role of energy recovery from residual waste in modern MSW management systems

Lidia Lombardi

Università degli Studi Niccolò Cusano, Italy

Waste management in Europe and North America is evolving towards sustainable materials management, intended as a systemic approach to using and reusing materials more productively over their entire life cycles. The increasing rate of recycle is bringing substantial and continuous improvement in environmental sustainability of waste management systems, especially focusing on Municipal Solid Waste (MSW), as documented by numerous Life Cycle Assessment (LCA) studies. However, among MSW, there is still a large part of residual waste – i.e. non-recyclable waste – which in many European regions are still landfilled, mainly because appropriate plants for their thermal treatment with energy recovery (i.e. Waste-to-Energy, WtE) are locally lacking, for historical opposition of local communities and political weakness, and/or for delays in the local economic development. This study has the objective to evaluate, by LCA approach, whether for increasing recycle rates of MSW, the introduction of WtE plants can contribute to improve or not the overall environmental sustainability of the MSW management system. To this aim a MSW management system, with separate material collection and recycling, was modelled and evaluated in reference to different levels of recycling rate, considering different options for the residual waste, namely landfilling with or without mechanical biological pre-treatment, WtE (without or with carbon capture from the flue gases) or more advanced options for energy/fuel recovery. The LCA results showed that the increased recycling significantly improved the environmental performances, but there is still room for improvement by the introduction of energy recovery. In particular WtE offers a solution to manage non-recyclable MSW and allows saving important resources (such as landfill volumes and non-renewable energy), reducing the contribution to global warming, and providing an essential contribution to fulfil the goals of a really sustainable waste management.

Economic Viability and Environmental Performance of Waste-to-Hydrogen Production: An Integrated Assessment of Gasification Pathways with Carbon Capture and Storage

Suviti Chari, Alex Sebastiani, Andrea Paulillo, Massimiliano Materazzi

University College London, United Kingdom

As the hydrogen economy develops, understanding both the economic feasibility and environmental implications of emerging production pathways becomes crucial. This study presents an integrated economic and environmental assessment of hydrogen production through gasification with carbon capture and storage (CCS) using three waste feedstocks: municipal solid waste (MSW), waste wood (WW), and mixed plastic waste (MPW).

The economic analysis reveals potentially competitive levelised costs of hydrogen (LCOH) across feedstocks for a 70 MWh plant in the UK (2023-based pricing). Capital costsare significant, with gasification and CO_2 capture comprising the major components. While MSW and WW benefit from carbon credits due to biogenic carbon sequestration, MPW incurs carbon taxes from fossil carbon emissions.

Sensitivity analyses demonstrate that waste-to-hydrogen processes exhibit greater resilience to market volatilities compared to conventional technologies. While electrolysis shows high sensitivity to electricity prices (£87/MWh variation), waste gasification pathways display modest variations (£6-8/MWh).

The integrated assessment reveals important trade-offs between economic and environmental performance. MPW demonstrates superior climate change mitigation (-289 kg CO_2 eq./MWh H_2), though costs remain high. However, only MSW and WW qualify as carbon removal technologies through biogenic carbon sequestration.

Waste-to-hydrogen processes become competitive with conventional steam methane reforming at carbon prices between £83-98/tCO_2. While blue hydrogen shows similar environmental performance but higher price sensitivity, green hydrogen offers superior environmental benefits but faces economic challenges (£231-286/MWh).

This research contributes to the emerging literature by demonstrating that waste-to-hydrogen technology, while constrained by feedstock availability, offers both environmental benefits and economic stability in volatile energy markets.

Development of a parametrised scale-up model for prospective life cycle assessment of an emerging pyrolysis-based technology, namely TCR® from laboratory to industrial scale

Sayara Saliyeva[1], Arnab Mukherjee[1,2], Katharina Reh[1], Matthias Franke[1]

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The transition towards sustainable waste management and renewable energy production necessitates the development of innovative technologies like Thermo-Catalytic Reforming (TCR®). TCR® is an emerging pyrolysis technology that converts biogenic waste into storable energy sources, namely biochar, pyrolysis bio-oil, and syngas. Despite its potential, there is a lack of comprehensive life cycle assessments (LCAs) that could anticipate environmental impact at the industrial level.

This study presents the development of a deterministic parametrised scale-up model for prospective LCA of TCR®. The data used in the study is from laboratory, pilot and demonstration-scale operations, and would be projected towards industrial-scale implementation. The model integrates key operational parame-

ters and scaling factors to assess environmental impacts at each size.

The parametrised model would allow for the adjustment of the parameters, providing flexibility to simulate various scenarios. Every parameter would be associated with parameter range and parameter change step size. The prospective LCA anticipates potential environmental impact associated with industrial scale TCR implementation in the horizon year, informing decision-makers about the implications of scaling up the TCR® technology.

By anticipating the environmental performance at industrial scale, technology developers can optimise the design and operation of TCR® facilities to enhance sustainability. This study contributes to methodological advancements in LCA by incorporating scale-up considerations and provides valuable insights into the deployment of emerging pyrolysis technologies.

Sustainability performance assessment in municipal solid waste management: evidence from Italy

Gabriella Arcese, Maria Giovina Pasca, Lidia Lombardi

Niccolò Cusano University, Italy

The study aims to evaluate the municipal solid waste (MSW) system's environmental and social sustainability in Italy to identify critical hotspots and potential for improvement.

Life Cycle Assessment (LCA) and Social Life Cycle Assessment (S-LCA) have been applied to an MSW management system following the ISO 14040-44, ISO 14075 standards and the UNEP 2020 Guidelines. The analysis focuses on a case study in Italy, analyzing the environmental and social impacts.

The results provide a valuable framework for assessing the environmental and social dimensions of waste management systems. Environmental sustainability performances show a comparison between different integrated MSW management systems. Findings highlighted how large benefits derive from increasing recycling and how the introduction of anaerobic digestion for the biogas/biomethane production from the biodegradable fraction of MSW improves the performance concerning simple composting; however, the largest benefits can be obtained by the introduction of energy recovery from the residual waste, in place of its landfilling, contributing significantly to reducing almost all the environmental impact indicators. In Italy, MSW management varies considerably across regions. Using LCA in this context highlights key challenges, such as the room for the improvement of environmental performances. More informed, fair and sustainable decision-making can be achieved by highlighting various environmental and social impacts of MSW management practices. Integrating LCA with S-LCA in MSW management systems improves the social well-being of workers and communities and contributes to the overall sustainability of urban areas by promoting fair and inclusive MSW management practices.

The study results support decision-makers in identifying environmental and social issues associated with MSW management systems. The approach promotes greater community involvement and a more equitable distribution of benefits from MSW management. More inclusive and sustainable systems reduce environmental impacts by optimizing resource use and promoting public health, job creation and social integration.

Life Cycle Assessment of Innovative Disposal Methods for Creosote-Treated Waste Wood

Mateusz Sydow[1], Katarzyna Klejnowska[2], Patrycja Kwaśniewska-Sip[1], Wojciech Cichy[1]

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This study focuses on the life cycle assessment (LCA) of three innovative methods for disposing of creosote-treated waste wood (1 – a hybrid method combining the pyrolysis process with the microbiological decomposition of the resulting pyrolysis oil; 2 - a bioremediation method using the metabolic potential of microorganisms and plants; and 3 - a composting method that leads to a useful product – compost), alongside two baseline scenarios (i.e. landfilling or incineration of waste wood) for comparative analysis. The research encompasses laboratory-scale LCA calculations based on the selected functional unit (disposal of 1 kg of creosote-treated waste wood) and LCA modeling using SimaPro software and two LCIA methods: ReCiPe 2016 Midpoint (H) and IMPACT World+ (Midpoint).

In the first step, any essential information regarding primary data i.e. resource consumption (chemical reagents etc.), emissions (e.g. gases during pyrolysis), and energy use for each method and baseline scenarios were quantified. For the landfill scenario, polycyclic aromatic hydrocarbon (PAH) migration to soil and air was evaluated under real atmospheric conditions over one year. In the incineration scenario, waste wood was burned in a 25 kW boiler equipped with emission monitoring systems to measure CO_2, CO, and CHx levels.

The comparison demonstrated the environmental benefits of the proposed methods over baseline scenarios, particularly concerning ecotoxicity, human toxicity, and greenhouse gas emissions. Baseline scenarios served as benchmarks to quantify the environmental impacts of unfavorable practices, providing a scientific basis for selecting more sustainable disposal methods. The findings contribute to advancing waste management strategies with lower environmental impacts.

This research was funded by the Polish National Centre for Research and Development under the Lider XIII program (contract no. LIDER13/0077/2022).

Transforming Waste: A Path to Sustainable Innovation

Marcella Volta[1], Katie Livesey[1], Peter Shonfield[1], James Tipper[1], Doyin Oladele[1], Gali Feldboy[2], Tato Bigio[2]

[1]ERM; [2]Manufacturing company

Companies are facing increasing pressure from customers and stakeholders regarding the environmental performance of their products. Meanwhile, greenhouse gas emissions (GHG) continue to rise, and numerous policies worldwide are aimed at promoting a circular economy and sustainable production. Although the implementation of circular economy principles and sustainable design can present challenges, companies must also demonstrate the effectiveness of their efforts through credible and robust assertions.

A global manufacturing company has developed a patented technology solution to address the growing waste challenge. This technology converts unsorted household waste into an innovative and thermoplastic composite that replaces oil-based resins in various manufacturing processes. The patented process diverts waste from landfills, thereby reducing emissions and resource consumption. This innovative patented process aims to close the loop between waste reduction and sustainable products by transforming waste into a polymer that replaces oil-based resins in durable and semi-durable applications across industries, all while utilizing a low-impact manufacturing process. To rigorously assess its environmental impact, the company commissioned ERM to conduct a life cycle assessment (LCA), which has been critically reviewed.

This paper highlights the potential of using Life Cycle Assessment (LCA) to illustrate the impact of the mentioned production and its related benefits. Such innovative composite not only has the capacity to replace

fossil-based plastic polymers, but also serves as an alternative disposal method for unsorted waste, which is typically sent to landfills. This process can significantly reduce landfill waste while producing a low-carbon product, serving as a compelling incentive for municipalities to invest in the technology. Such investment not only reduces emissions but also minimizes the physical footprint of landfills.

Session 1.24: LCA & Circularity to Improve Road Construction Env. Performance Part II

Time: Wednesday, 10/Sept/2025: 4:30pm - 6:00pm
Session Chair: Nicolás Héctor Carreño Gómez, VINCI Construction Shared Services GmbH, Germany
Session Chair: Davide Lo Presti, Universita degli studi di Palermo, Italy

Identifying the most sustainable road bridge design

Martina Serra[1], Yunus Harmanci[2], Amirhossein Mohammadi[3], Roland Hischier[1], René Steiger[2]

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The construction sector contributes over 20% of Switzerland's total CO2 emissions, primarily due to its reliance on CO2-intensive materials, making it a critical focus in the transition to net-zero goals. As part of the SCENE (Swiss Center of Excellence on Net-Zero Emissions) project, this research focuses on the development of solutions for a net-zero emissions bridge within the road infrastructure.

This study explores alternative road bridge designs, focusing on two-lane decks with one to two spans and total lengths between 10 m and 80 m located in Switzerland. A single and two-span slab bridge model, initially focusing on the load-bearing structure and developed using SOFiSTiK finite element modelling software, serves as the basis for this analysis. The modeling approach allows for systematic optimization by parametrizing variables such as span length, cross-sectional thickness, and material selection, enabling the simulation of numerous design alternatives. The designs are first evaluated for compliance with structural guidelines for safety, durability, and robustness. Only those designs and material combinations that meet structural verifications are in a second step then further evaluated from their environmental perspective.

To assess the environmental implications, the life cycle assessment (LCA) methodology is applied, using the ecoinvent database as background data source. We investigate different material combinations to identify alternatives that allow to reduce environmental impacts while remaining applicable in the various bridge configurations. Data derived from the bridge models resulting from the first step, including the quantities of materials (e.g., concrete,steel), are used as basis for the life cycle inventories. The results allow to identify the most sustainable bridge design options, highlighting the preferred materials and their optimal combinations based on their environmental performance. Ultimately, these findings will allow to guide the selection of bridge designs in the Swiss construction sector that reduce CO_2 emissions while meeting structural and functional requirements.

Life Cycle Assessment of Using Copper Slag as an Aggregate Replacement in Asphalt Mixtures for Single Surface Treatment

Danilo Bianchi Granato, Pia Wiche

EcoEd, Chile

The road construction sector demands significant quantities of aggregates, and the mining industry in Chile produces 40 million tons of copper slag (iron silicate) annually. Replacing natural aggregates with this mining waste offers potential to reduce the environmental impacts of aggregate extraction and address mining-related environmental liabilities.

This study employs LCA to evaluate the environmental trade-offs of using copper slag in asphalt mixtures for a single surface treatment covering 100 m^2 of roadway. The analysis follows ISO 21930, EN 15804, and

PCR 2019:14, assessing ten impact categories across stages A1-A4. The baseline scenario of 100% natural aggregates is compared to a scenario where 100% of aggregates are replaced with copper slag. Additionally, two economic allocation scenarios for copper production are considered.

Results indicate that using copper slag without allocation (zero value) increases impacts by up to 20% in five categories but reduces them by 15% to 50% in four categories. These results are attributed to the need for increased asphalt emulsion to maintain material properties when using slag, which offsets benefits from avoiding natural aggregate extraction or slag disposal.

When copper slag is assigned a market value (considered a by-product), it receives impacts from copper production, resulting in higher impacts across all categories. Impacts also increase when slag is transported over longer distances compared to natural aggregates, a likely scenario given the centralized production of this mining waste.

This study highlights the nuanced benefits of substituting natural aggregates with copper slag in asphalt mixtures. Discussions should focus on the conditions for its environmental viability, emphasizing cost scenarios and short transportation distances. The findings raise broader questions about integrating secondary materials into road construction, such as balancing trade-offs in material properties, transportation logistics, and circular economy principles. These aspects are critical to advancing sustainability in road construction practices.

Preliminary cradle-to-gate life cycle assessment of bio-based materials as fossil-based bitumen alternatives based on the Dutch Environmental Cost Indicator (ECI) scoring system

Christian Gerald Daniel, Blanca Corona, Ric Hoefnagels, Martin Junginger

Universiteit Utrecht, The Netherlands

This study serves as a preliminary environmental impact assessment of 13 bio-based materials to substitute fossil-based bitumen with the case study of the Netherlands using cradle-to-production gate life cycle assessment based on EN 15804 +A1 and +A2 norms, which utilise the CML Midpoint and EF impact category methods, respectively. The outcome is monetised using the environmental cost indicator (ECI) score governing in the Netherlands. The functional unit chosen is 1 ton of 13 feedstocks, ranging from plant-based oils (corn, castor, soybean, rapeseed, jatropha, linseed, and tall oils—pitch, rosin, and rosin ester), guayule rubber, bio-oil and char from forest residue, and used cooking oil. The result shows that the ECI score of the fossil-based bitumen is lower than that of the bio-based feedstocks when the biogenic carbon dioxide sequestration effect is excluded, with two exceptions being biochar and purified used cooking oil using the new +A2 method (€67.5 and €19.5 vs €80.3 / ton for bitumen). The variety in the outcome stems mainly from the emphasised toxicity factors (human and marine aquatic ecotoxicity) in the CML vs climate change (fossil and biogenic) in the EF methods, translated to their respective ECI coefficients. Taking into account the biogenic carbon storage (BCS) effect brings more materials that have lower scores than bitumen, such as tall oil products (pitch, rosin, and rosin ester), bioethanol from the solvolysis process, and several plant-based oils (soybean, rapeseed, linseed, and jatropha oils). The feedstocks with the lowest total ECI scores are used cooking oil, biochar, tall oil pitch, and tall oil rosin in all cases.

Implementing Life Cycle Management of road pavements in Europe

Gabriela Buttitta[1], Ana Carrion[2], Joao Santos[3], Salvatore Biancardo[4], Davide Lo Presti[1]

[1]University of Palermo, Italy; [2]University of Granada, Spain; [3]University of Twente, The Netherlands; [4]University of Naples Federico II, Italy

This research addresses the challenges road authorities (RAs) face in managing pavement networks while considering sustainability. By using a life cycle approach, the study looks at the long-term effects of decisions and encourages continuous improvement. It provides detailed guidelines for implementing Life Cycle Management (LCM) of road pavements, developed for the Conference of European Road Directors (CEDR). These guidelines help define the goals and scope of a study and evaluate environmental, economic, and social impacts using Life Cycle Assessment (LCA), Life Cycle Costing (LCC), and qualitative societal indicators. They also suggest a Multi-Criteria Decision Analysis (MCDA) approach for interpreting results. Since LCA and LCC require extensive data, the study proposes using Building Information Modelling (BIM) to streamline data collection and offer a more integrated management approach. The ultimate goal is to make LCM a standard practice for RAs, supporting the development of sustainable transportation infrastructure.

Data collection tool for cradle-to-gate Life Cycle Sustainability Assessment for asphalt mixtures using alternative paving materials

Thomas Mattinzioli[1], Gabriella Buttitta[2], Joao Do Santos[5], Pamela Haverkamp[4], Emmanuel Chailleux[3], Davide Lo Presti[2], Ana Jiménez del Barco Carrión[1]

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Life Cycle Sustainability Assessment (LCSA) is a crucial methodology for evaluating the environmental, economic, and social impacts of asphalt mixtures. However, data collection for LCSA remains a labor-intensive and complex task, particularly when alternative paving materials are used. The lack of standardized approaches and user-friendly tools makes the process challenging for practitioners, often leading to inconsistencies and difficulties in data harmonization. Ensuring reliable and comparable results requires a systematic and streamlined approach to data collection.

To address these challenges, a dedicated data collection tool has been developed to support the cradle-to-gate LCSA of asphalt mixtures. This tool provides a structured framework that simplifies the process, enhances data quality, and ensures consistency across different assessments. By guiding users through the required data inputs in a clear and intuitive manner, the tool reduces the complexity and effort associated with LCSA implementation. Additionally, it facilitates the integration of alternative paving materials into the assessment, promoting a more comprehensive understanding of their sustainability performance.

In this work, the features and functionalities of the data collection tool are presented, highlighting its potential to improve efficiency and reliability in sustainability assessments. A case study is used to illustrate its application, demonstrating how the tool streamlines data gathering and enhances comparability in asphalt mixture evaluations. The results emphasize the importance of standardized data collection in achieving more robust and transparent sustainability assessments. By simplifying and harmonizing the LCSA process, this tool contributes to the broader adoption of sustainable practices in pavement design and construction.

This work is part of RILEM Technical Committee Alternative Paving Materials – Sustainability.

Innovative Bio-Based Method for Sustainable Road Rehabilitation: Advancing Circular Economy Principles

Mehrdad Ghorbani Mooselu[1], **Mafalda Silva**[1], **Tonje Norheim**[2]

[1]NORSUS, Norway; [2]Carbon Crusher Norge AS, Norway

Road construction and rehabilitation activities present significant environmental challenges mainly due to high resource requirements and their associated embodied emissions. During the last years, there has been an increased focus on assessing the potential for increased material circularity within the building sector, and different pavement recycling road rehabilitation methods have been considered and tested. However, there are a limited number of published studies assessing whether these methods lead to lower environmental impacts from a life cycle perspective.

The Carbon Crusher Bio-Road is a novel road rehabilitation technique combining cold-in-place recycling and stabilization using a bio-based binder. The process reuses all existing road materials within the road's structure, minimizing the need for new raw materials and reducing waste generation, hence addressing and applying the circularity principles. The steps include material crushing, binder application, grading, compaction, and final profiling to enhance the road's mechanical stability, load-bearing capacity, and resistance to deformation. This approach is applicable to both paved and unpaved roads with different traffic load.

This study aims to evaluate the environmental impacts of Carbon Crusher Bio-Road, from a cradle-to-grave life cycle perspective. Results show significantly lower impacts, especially for climate change which is primarily attributed to the use of a bio-based binder. This highlights the potential of bio-binders to offset emissions in pavement recycling road rehabilitation projects.

The findings indicate the feasibility of integrating circularity into road rehabilitation projects through innovative materials and processes, while maintaining technical performance and cost efficiency. The study underscores the importance of sustainable road design, recycling technologies, and LCA role in achieving decarbonization goals. Additionally, it contributes to the ongoing development of sustainability metrics for road rehabilitation and provides a replicable model for achieving nature-positive road design in alignment with circular economy principles.

Session 2.01: Pathways to Net-Zero: Industrial Decarbonization & Green Energy Part II

Time: Thursday, 11/Sept/2025: 9:35am - 11:05am
Session Chair: Nele De Belie, Ghent University, Belgium
Session Chair: Pascal Di Croce, EuLA, Belgium

Decarbonizing Steel – Harmonizing Product Carbon Footprint and CBAM Assessment Methodologies

Rajesh Kumar Singh, Ritesh Agrawal, Kalpeshkumar Prajapati

Sphera India Private Limited, India

The iron and Steel sector is one of the prominent sectors wherein the environmental footprint of a product has been extensively assessed and published applying various standards such as Life Cycle Assessment (ISO 14040 and ISO 14044, EU-EF Initiative), product carbon footprint (ISO 14067, PAS 2050, ISO 20915), Environment Product Declaration (ISO 14025), etc. These standards essentially follow the value chain (cradle to gate/grave) assessment of various environmental impact categories having different system boundaries, unharmonized methodologies, and reporting practices. The Carbon Border Adjustment Mechanism (CBAM) is an environmental policy tool that supports the EU climate ambitions of reaching climate neutrality by 2050 at the latest. Under CBAM regulation, reporting of GHG embedded emissions for CBAM goods (Iron and Steel, Aluminium, Fertiliser, Hydrogen, and Electricity) is obligatory for Reporting Declarations (EU Importers) from the non-EU manufacturers. CBAM methodology functions similar to product carbon footprint but has a narrower system boundary. It includes disclosure of direct and indirect emissions from the defined system boundary of the CBAM goods. CBAM methodology brings another layer of complexity to the existing standards and methods in terms of exclusions and inclusions in the system boundary. Accounting of GHG-embedded emissions will help these companies to track their emissions performance, compare and benchmark their performance against best practices, and identifying GHG emissions reduction opportunities for future technological options. In this context, a Steel HRC produced via BF-BOF and DRI-EAF route has been selected and the product carbon footprint as per ISO 14040/44, ISO 14067, EU-PEF, EPD-PCR of steel product and CBAM method were assessed for various system boundary conditions to identify the influencing factors on product carbon footprint and bring alignment in disclosures. Additionally, this study highlights the major methodological challenges and helps decision makers to understand the reporting claims coherently.

Comparative LCA of Refinery Products: Naphtha, Propylene & Benzene (Fossil vs Circular)

Fernando Guerra[1], Rafael Carrion[1], Cesar Galera[1], Jasmin Hengstler[2], Usama Khalid[2], Oliver Schuller[2]

[1]Moeve, Spain; [2]Sphera, Germany

Cepsa/Moeve´s refinery products are primary feedstocks for many downstream products. Cepsa/Moeve commissioned Sphera to perform an attributional cradle-to-gate study of selected refinery products produced in two of Cepsa/Moeve's energy parks in Spain, quantifying the environmental performance. The study is based on primary, quality-assured, and up-to-date life cycle data. It has been conducted in accordance with ISO 14040:20061, ISO 14044:20062, and ISO 14067:20183 with respect to data quality, completeness, and consistency. The study has been critically reviewed in accordance with ISO 14071:2024 by three external independent experts.

For each of Cepsa/Moeve's facilities, the production of the following refinery products has been analyzed:

fossil benzene, circular benzene, fossil naphtha, circular naphtha, fossil propylene and circular propylene. The selected fossil refinery products were produced from virgin feedstocks like crude oil while the circular refinery products were produced from co-processing of the circular feedstock pyrolysis oil (PO) and crude oil. PO was produced from plastic waste.

The production of a circular refinery product represents a multi-functional process i.e., producing circular refinery products and recycling of the plastic waste. Comparing the multi-functional product systems of the circular refinery products to the mono-functional product systems of the fossil refinery products would be incomplete. To solve this problem, the mono-functional product systems of the fossil refinery products were expanded by the treatment of plastic waste ("system expansion by addition").

For both refineries, circular refinery products showed better results for the impact categories "Climate Change – total", "Climate Change – fossil", "Acidification", "Photochemical ozone formation" and "Resource use, fossils".

We would be pleased to share details on methodological challenges encountered, the approach chosen and present first hand Product Carbon Footprint results of our circular products compared with conventional products at the LCM 2025.

Well-to-Wake Prospective Life Cycle Assessment of Synthetic fuels for the Maritime sector in the North Sea

Aza Pedraza Zulma Karina, Komal mallesh chougule, Gomez Trillos Juan Camilo, Brand-Daniels Urte, Thomas Vogt

DLR (German Aerospace centre), Germany

The utilization of synthetic fuels produced from renewable sources has been considered an alternative to lowering maritime sector emissions. Nevertheless, the processes involved in the supply chain from the production location to the bunkering port represent a significant challenge due to the additional emissions from these processes to the synthetic fuel consumption. A prospective life cycle assessment (pLCA) is crucial for defining environmental hotspots of Well-to-Wake and how the results can change regarding the increasing shares of renewable sources in the 2030 electricity generation scenario and compare to the base case scenario using the current electricity mix.

Therefore, this contribution focuses on a case study using pLCA for Well-to-Tank (WTT) and Tank-to-Wake (TTW) scopes. WTTincludes e-hydrogen, e-ammonia and e-methanol pathways produced in Germany and shipped to The Netherlands as a final bunkering port. Compression, e-ammonia and e-methanol synthesis, storage, transportation, cracking and dehydrogenation were considered to analyse the impacts. Moreover, for the TTW scope, utilization of e-hydrogen in a Roll-on/Roll-off Ship with Proton Exchange Membrane fuel cell (PEMFC) or Internal Combustion Engine (ICE) to produce electricity for a Roll-on/Roll-off Ship for a round trip (RT) from Rotterdam to Inmingham, UK. The results reveal that for the WTT scope, the e-methanol pathway has the highest global warming potential (GWP) impact (0.067 kg CO2 eq /MJLHV), followed by e-ammonia (0.058 kg CO2 eq /MJLHV). Finally, the e-hydrogen pathway has the lowest GWP impact (0.029 kg CO2 eq /MJLHV) for the base case scenario. On the other hand, ICE represents the technology with the highest GWP impact (142 ton CO2 eq /RT), compared to the PEMFC (133 ton CO2 eq /RT). In addition, increasing shares of photovoltaic and wind electricity sources by the 2030 scenario will reduce GWP emissions by 57%, 66% and 55% for the e-hydrogen, e-ammonia and e-methanol pathways, respectively

Life cycle assessment of CO2 utilization technologies: Methodological approaches and findings

Jinjoo An[1], Yuree Kwon[1,2], Jina Choi[3]

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As the urgency to reduce greenhouse gas emissions intensifies for high-emission industries striving for carbon neutrality, the need for innovative low-carbon technologies, such as carbon capture and utilization (CCU), which can be seamlessly integrated into existing industries has become increasingly critical. In addition, the enforcement of stringent international policies regarding accounting embedded greenhouse gas emission of products and processes underscores the importance of a holistic environmental assessment, such as life cycle assessment (LCA). LCA is particularly advantageous for evaluating CCU technologies, where conventional greenhouse gas inventory methodologies, such as those outlined by the IPCC Guidelines, encounter challenges due to complex system boundaries and the lack of standardized approaches tailored to those technologies. In this presentation, we delve into the methodological conflicts that arise during carbon footprint evaluation or LCA of CCU technologies. We further demonstrate how varying decision-making approaches to resolve these conflicts lead to significant differences in assessment outcomes, illustrated through case studies. To address these conflicts and ensure transparent decision-making, the Korea Research Institute of Chemical Technology developed comparative LCA guidelines that reflect the unique characteristics of CCU technology and a carbon footprint methodology tailored to each product. These findings highlight the importance of methodological consistency and transparent decision-making in advancing the credibility and applicability of LCA for emerging low-carbon technologies.

A holistic view of ammonia micro gas turbine – the role of Life Cycle Assessment

Karolina Petela, Mateusz Proniewicz, Andrzej Szlęk

Silesian University of Technology, Poland

Reliable, dispatchable, decarbonized energy conversion systems are a future-must, if the Paris Agreement goals should be fulfilled and net-zero transformation shall happen. It is expected that they will rely on a sustainable, carbon-free fuel substituting conventional fossil fuels. A great candidate could be ammonia. It is perceived as a hydrogen vector coming from renewable sources, which is easier to store and transport than pure hydrogen. Operationally flexible and a good option for cogeneration applications utilizing ammonia might be micro gas turbines (MGT) fuelled by ammonia-hydrogen mixtures. As a novel and emerging technology, its development comes with challenges connected to the thermoacoustic behaviour of NH3-H2 blends, flame-wall interaction and NOx and N2O emissions. This is addressed by researchers working together in an international research project on Ammonia-Hydrogen Combustion in Micro Gas Turbines ADONIS (EIG Concert Japan programme). One of the main aims of the project is to present this sustainable hydrogen technology as affordable and clean energy. It is indispensable to assess the environmental sustainability potential of every system based on carbon-free labelled fuel in terms of the whole life cycle of the technology. A standardized Life Cycle Assessment (LCA) is applied to quantify the environmental and health impacts associated with all stages of ADONIS technology. The LCA considered in this research presents a comparative analysis of two residential MGT cogeneration systems. One is fuelled by ammonia, while the reference system utilizes natural gas. All: construction phase, fuel production phase, operational phase and end-of-life are considered. The environmental impact indicators are translated following both ReCiPe method and Environmental Footprint method. Taking from results, the environmental profile of ammonia production is not competitive, however, the expected compensation by the exploitation phase seems promising. An inspiring discussion is devoted to the meaning of setting the system boundaries and completeness of Life Cycle Inventory.

Cumulative Energy Demand and Greenhouse Gas Reduction Potential of Alternative Maritime Fuels: A Life Cycle Assessment Approach to Maritime Decarbonization

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Energy Studies Institute, National University of Singapore, Singapore

Maritime transportation plays a crucial role in global trade, but its environmental impact has come under increasing scrutiny. As the sector faces mounting pressure to reduce its carbon footprint, decarbonisation has emerged as a key priority to meet stringent emissions reduction targets. This study presents a comprehensive examination of the cumulative energy demand (CED) associated with two primary fuel switch options for marine decarbonisation: biofuels and hydrogen derivatives, utilising a life cycle assessment (LCA) approach.

The research evaluates the supply chain of alternative fuels, encompassing raw material extraction, fuel generation, distribution, and utilization. This holistic approach is essential for assessing fuel switch options, comparing greenhouse gas reductions with energy demand, and identifying potential consequences for land-based decarbonization strategies. By analysing CED, the study provides a valuable indicator of the primary energy requirements resulting from fuel switch initiatives, which may significantly impact a country's overall energy demand and its own decarbonization journey.

The biofuel evaluation measures energy needs and carbon investments, such as fertilizer and machinery use, for various feedstocks and production pathways. Additionally, the energy profiles of hydrogen derivatives, such as green ammonia, are assessed based on their manufacturing processes.

The study aims to provide insights into the greenhouse gas reduction potential of fuel switches compared to traditional marine fuels, as well as their corresponding CED profiles. Furthermore, it identifies potential hotspots within the supply chain, offering valuable information for decision-making processes. By presenting a comprehensive analysis of the energy demands and environmental impacts associated with marine decarbonization options, this research contributes to the development of sustainable and effective strategies for reducing the maritime sector's carbon footprint.

Exploring Feasibility of Life Cycle Sustainability Assessment for Decarbonizing Waste-to-Energy Systems: Global Insights and Developing Country Perspectives

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[1]The University of Tokyo, Japan; [2]NIES Social Systems Division, Japan; [3]NIES Center for Climate Change Adaptation, Japan; [4]NIES Material Cycles Division, Japan

Purpose: This study evaluates the feasibility of Life Cycle Sustainability Assessment (LCSA) as a framework for assessing Waste-to-Energy (WtE) technologies, aiming to support global decarbonization efforts. The purpose is to provide insights into current technology performance, while addressing regional variations and the specific challenges faced by developing countries.

Methods: A systematic literature review of 61 peer-reviewed articles was conducted. Key performance data for WtE technologies (e.g., energy efficiency, GHG emissions) and framework characteristics were extracted and analyzed. This review focused on identifying the strengths and limitations of current assessment practices when applied to diverse global contexts, from high-income nations to low-resource settings.

Results: The review confirms that incineration is the most prevalent WtE technology, achieving energy recovery efficiencies of 20–55% with moderate GHG emissions (359–650 kg CO2/tonne). However, its feasibility in developing countries is hindered by challenges like high organic waste fractions and fragmented poli-

cies. The analysis also reveals that emerging technologies like gasification, which can achieve net-negative emissions (-200 kg CO2/tonne), and circular economy principles such as advanced emissions control and ash recycling are critical but underrepresented in current assessments.

Conclusion: While the existing LCSA provides a systematic approach, its direct application is challenged by regional disparities. The feasibility of using LCSA for WtE decarbonization depends on its ability to adapt. This research highlights the need for a more dynamic LCSA framework that integrates emerging technologies and circular economy principles, thereby providing a more robust tool for informed decision-making in both developed and developing countries.

Life Cycle Management of an Emerging Primary Aluminium-air Battery for Seasonal Energy Storage

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Aluminium has the potential to act as an energy carrier in the energy transition due to its ability to store renewable electricity and facilitate re-electrification through Al-air batteries. During this process, aluminium is converted to its oxides, which can subsequently be reduced, enabling a charge-discharge cycle within a circular usage framework. Beyond its role as an energy carrier, aluminium is a lightweight, functional, and strategic material essential for developing sustainable technologies. As the aluminium industry shifts toward green production, improvements across the production process and supply chain become imperative. This study evaluates aluminium's potential as an energy carrier for seasonal energy storage, addressing simultaneous electricity and heat supply. The analysis adopts a life cycle assessment (LCA) approach to examine the environmental sustainability of aluminium and Al-air battery from raw material extraction to end-of-life, focusing on the life cycle management. In addition to conventional primary aluminium production pathways, the study incorporates future scenarios involving decarbonized production methods. The LCA results suggest that decarbonized primary aluminium can serve as an environmentally sustainable energy carrier, particularly in the global warming impact category, comparable to hydrogen and other long-term energy carriers. However, trade-offs were observed, notably a significant increase in abiotic resource depletion. This increase is primarily driven by the use of metals in inert anodes, a critical component of carbon-neutral aluminium electrolysis. These findings underscore the dual challenges and opportunities in leveraging aluminium as a key enabler in the energy transition while highlighting the importance of advancing sustainable production practices across its life cycle.

Reducing environmental impacts of water electrolysis systems by reuse and recycling - Life cycle assessment of a 5 MW alkaline water electrolysis plant

Annika C. Hoppe, Christine Minke

Clausthal University of Technology, Germany

Decarbonizing industrial processes is essential for achieving sustainability, with green hydrogen emerging as a crucial solution in this transition. Our study examines the application of Life Cycle Assessment (LCA) methodologies to quantify the environmental benefits associated with a 5 MW alkaline water electrolysis (AWE) system, focusing on developing recycling strategies for both stack and balance of plant components. While previous LCAs have analysed AWEs, they do not provide a detailed view of the end-of-life (EoL) phase. Additionally, initial ideas regarding recycling strategies for AWE stacks are not integrated in LCA studies so far, resulting in a significant research gap in understanding the environmental impacts and material savings associated with reuse and recycling of components in AWE plants. Our research specifically emphasizes the critical raw material nickel, which serves as a catalyst for the chemical reaction within the AWE system. By optimizing the resource utilization of nickel through closed-loop recycling, this study highlights how systematic approaches can substantially reduce the global warming potential (GWP) of hydrogen production. Our findings reveal that manufacturing AWE systems with recycled content can achieve up to a 50 % reduction in GWP compared to the use of virgin materials. By integrating comprehensive EoL considerations into LCA methodologies, this study underscores the potential for material recovery and component reuse after a 20-year operational lifespan. Notably, 77 % of materials within the AWE system can be recycled or reused, reinforcing the need for continued research and advancement in recycling technologies. Ultimately, this study contributes valuable insights for decarbonizing industrial processes and demonstrates how innovative recycling methods can effectively lower carbon footprints and enhance resource security in the context of a green hydrogen economy.

Session 2.02: Life Cycle Metrics for industry and policymakers: From Innovation to Integration II

Time: Thursday, 11/Sept/2025: 9:35am - 11:05am
Session Chair: Luca Zampori, PRé Sustainability, The Netherlands
Session Chair: An De Schryver, PRé sustainability, The Netherlands

Integrating life cycle assessment into the V-model for cyber physical systems for ecodesign purposes

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With the ever-growing complexity of technical products and accelerating development cycles, the process of innovation has been increasingly formalized in the past. In such, the V-model as described in VDI 2206 is an established model to describe the engineering process of cyber physical systems and is applied in many industries. Since the reporting of environmental performance indicators will be requested in the future from both regulatory bodies and customers, integrated and reliable ecodesign processes will be decisive. Especially the need for up-to-date data for life cycle assessments (LCA) of the product under development is a major challenge. Herein, the existing formalization of design processes provides opportunities to LCA practitioners in including the requirements and structure of LCAs.

In the presentation, a V-model for LCA is introduced, providing engineers and LCA practitioners with a model that can be integrated into existing processes. The V-model from VDI 2206 and the LCA method from ISO standards 14040 and 14044 are combined into an engineering ecodesign method for LCA, unifying the two disciplines. Every design stage comes with its requirements for LCA data while a holistic assessment of the entire product life cycle must be conducted. Hence, the presentation will discuss a three-tiered approach allowing to integrate LCA into product development based on the V-model. Timeslots for continuous data exchange in the design process are defined to create synergies between design and LCA. Partial LCA results can be provided at different times in the design process to allow for close alignment and thus results that are available for individual design decisions. The efficient and automated data collection by creating interfaces between design applications and LCA by building on the V-model is discussed. Thus, the approach provides designers with an implementable, ready to use method of integrating LCA into product design at any design stage.

Applying New Time-Integrated Approach for Biodiversity Footprint To Cosmetic Sector: Case Study Of l'Oréal

Magdalena Czyrnek-Deletre[1], Margot Rigal[1], Emma Garrigues[1], Aude Dupin[1], Alexis Burguburu[1], Jacques L'Haridon[2], Guillaume Neveux[1]

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Various industries, particularly the cosmetic sector, depend on natural resources to produce their products. As biodiversity declines globally, it is essential to include the biodiversity footprint in product eco-design. Many approaches are in use, but no consensus exists on which should be endorsed.

I Care has been working since 2017 on developing a methodology to assess the impact of products on biodiversity. L'Oréal participated in the development of this methodology, called Product Biodiversity Footprint (PBF), which was published in 2019. L'Oréal aims to develop an understanding of the biodiversity footprint at the product level to support the eco-design of cosmetics that preserve or even restore biodiversity, and

to explore its connection to corporate commitments.

In 2024, the PBF methodology underwent significant changes by incorporating the Mean Species Abundance metric to assess biodiversity loss. Based on the 2019 Global Assessment report from the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, a new approach for weighting biodiversity pressures was proposed. The method assesses the time-integrated impacts on biodiversity from climate change, land use, pollution, and water use, comparing a reference product with its more sustainable variation.

The focus of this study was on three cosmetic products: a shampoo, a shower gel, and a deodorant. The analysis was conducted at two levels: the ingredient level (including glycerin, sodium laureth sulfate, cocamidopropyl betaine, ammonium lauryl sulfate, and ethanol) and the agricultural feedstock level (considering palm, coconut, soybean, and beetroot crops). The study incorporated more specific farming practices into the model, such as whether the ingredients were sourced organically or sustainably from specific locations. The results indicate a difference in the impact between petrochemical-sourced ingredients and those sourced sustainably. In some cases, sustainably sourced ingredients have a more favourable impact, depending on the type of feedstock and the specific agricultural practices employed.

Harmonizing environmental life cycle assessments of solar thermal energy systems: Methodology guidelines from the IEA Solar Heat and Cooling Programme Task 71

Hanna Kröhnert, Sabine Frei, René Itten

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Despite efforts of decarbonization, the global heating sector is still dominated by fossil fuels. As of 2022, only 13% of the global heating demand was covered by renewable energies. To achieve the international climate protection targets, the integration of renewable energies in the heating sector must be considerably accelerated.

Solar heating and cooling (SHC) systems are considered as clean energy sources that can significantly contribute to decarbonizing the heating sector. In recent years, new SHC technologies have emerged, conversion efficiencies have increased, and new large district heating and process heat projects have been realised. Furthermore, the integration of SHC systems with other technologies, such as heat pumps, photovoltaic-driven heating/cooling, and condensing fossil combustion, has created new opportunities for sector coupling and optimization.

To evaluate the energy and environmental performance of these diverse SHC systems, Life Cycle Assessments (LCA) play a crucial role, assessing the entire lifecycle from production to end-of-life treatment. However, there is currently no established standardized methodology for LCA of SHC systems, making comparisons between technological solutions challenging.

The Task 71 of the IEA Solar Heating and Cooling program addresses this gap by fostering a shared understanding of SHC technology assessments. The main goal of Task 71 is to develop methodological guidelines for assessing the economic and environmental impacts of SHC systems. Furthermore, it seeks to establish a publicly accessible database that includes country-specific heat demand systems, and the life cycle inventories for corresponding SHC systems and components.

At the LCM 2025, the consolidated LCA methodology guidelines for SHC systems are presented, including an application example for the comparison of single and multi-family homes in central Europe. Key methodological aspects cover decisions on system boundaries, functional unit, allocation of impacts, recommended impact assessment methods as well as reporting requirements for LCA results to facilitate informed, evidence-based decision-making.

Bridging systematic, digital and physical sustainability: How LCA guides the path to the development of more sustainable electronic products.

Lukas D'Olif, Jonathan Demierre

Helbling Technik Wil AG, Switzerland

The advancement of smart and digital technologies has transformed modern life. However, this progress comes with increasing environmental costs – ranging from resource-intensive electronics manufacturing to energy-demanding data centers. At the same time, intelligent electronic products have the potential to enhance efficiency and thus contribute to environmentally sustainable development. To ensure this potential leads to real sustainability, a holistic, quantitative framework such as life cycle assessment (LCA) is needed, which integrates systemic, digital, and physical dimensions to guide effective improvement strategies.

Connected electronic devices often rely on background-processes like cloud storage, data transfers, and AI services that run in energy-intensive data centers. A system-level LCA can uncover the primary contributors to their environmental footprint and connect these impacts to specific product features, such as geographical and time-wise access to cloud storage or redundant system architecture. When such insights are considered as early as in the ideation phase of a product, considerable amounts of energy can be saved.

At the product level, eco-design strategies for electronics are a crucial starting point. Using a parametric product LCA tool developed in collaboration with the industry, the environmental footprint of electronic devices can be accurately quantified, enabling data-driven design optimizations that address material use and manufacturing processes.

To build truly sustainable systems, these assessments must be interconnected. Changes at one level - whether system, digital, or physical - inevitably affect the others, underscoring the need for integrated analysis. By modeling and iterating across these layers, optimal system configurations can be developed, advancing meaningful progress toward sustainability.

A Multi-Criteria Decision-Making tool to be used in Green and Circular Public Procurement

Nicolas Bertoldo[1], Mette Alberg Mosgaard[2], Anja Marie Bundgaard[2], Giovanni Dotelli[1]

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Public procurement is a pivotal component of governmental activities and economic systems worldwide. In the European Union (EU), member states spend an average of 14% of their GDP on procuring goods and services. By selecting environmentally friendly and circular products, public authorities (PAs) can promote these solutions and reduce overall environmental burdens. This approach, known as Green Public Procurement (GPP), aims to achieve sustainability by prioritizing products and services with lower environmental impacts and long lifetimes. The EU is actively developing environmental and circular criteria for various product and service categories.

The objective of this study is to develop a methodology to support PAs in selecting the most circular and environmentally sustainable products and services in public procurement, through the adoption of e.g. EU GPP requirements. The main outcome of this work is a web application tool which can be integrated into the public procurement decision-making process. The tool allows a simple, transparent and reliable assessment of compliance with the designated criteria. It serves to facilitate an efficient comparison of different bids within the public procurement decision-making process. Moreover, the tool allows tenderers to provide necessary data and upload supporting documentation, enabling public authorities to efficiently evaluate bids against selected criteria. The comparison is then made considering whether the selected criteria are satisfied, and a preliminary ranking of the bids is made according to the compliance levels with the se-

lected award criteria.

As a first implementation, the methodology considers the furniture category, taking into account the EU requirements, as well as specific defined criteria based on Life Cycle Thinking, focusing on circularity and environmental aspects.

By providing a standardized approach to GPP implementation, this study contributes to the broader EU objective of fostering a resource-efficient economy and stimulating demand for more sustainable goods and services.

Developing a Standardized Life Cycle Assessment Methodology for Higher Education Institutions: Addressing Data Gaps and Enabling Comparability for a Sustainable Development

Constantin Keul, Venkateshwaran Venkatachalam, Sebastian Spierling, Hans-Josef Endres

Leibniz University Hannover, Germany

Higher education institutions (HEIs) play a crucial role both as a source of environmental impact and in fostering sustainable development through education, research and innovation. Despite their significance, there is a lack of comprehensive methodological frameworks for assessing the environmental impacts of HEIs using life cycle assessment (LCA). Existing approaches are challenged by the diversity of HEIs in terms of size, infrastructure, teaching formats, and activities, as well as by limited data availability and inconsistencies in application. These issues hinder meaningful assessments and comparisons.

To address these challenges, a literature review was first carried out. In addition to analysing different assessment methodologies, system boundaries and other, the focus was placed on the type of data collection and the identification of typical data gaps. Based on these findings, an initial case study will be carried out, which creates the basis for the further development of a new LCA methodology for HEIs. This methodology builds on established LCA standards, and provides structured guidance for goal and scope definition, inventory analysis, and impact assessment. It accounts for the unique characteristics of HEIs, such as the balance between on-campus and online activities, integration into urban or rural contexts, and the allocation of impacts from diverse operations, including economic activities as well as teaching, research, travel, or canteen operations.

By offering a standardised framework, a new LCA methodology aims to enhance the applicability, consistency, and comparability of LCA studies for HEIs. It also lays the foundation for extending the assessment to cover social and economic dimensions in the future, supporting the transition toward a holistic life cycle sustainability assessment. This approach enables universities to systematically identify and continuously improve their environmental impact and potential hotspots, while strengthening their role as pioneers of sustainable development.

Towards closing the implementation gap: an analysis of decision making in reusable packaging systems.

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Packaging plays a vital role in containing and safely distributing goods globally. However, the predominance of single-use packaging in the current 'take-make-dispose' economic paradigm has led to significant environmental challenges, including waste generation, pollution, and unsustainable resource extraction. Reusable packaging is proposed as a solution that can potentially enhance material circularity while offering positive economic performance. However, it requires transitioning to collaborative Circular Business Models (CBMs), along with restructuring supply chains. This systemic change involves a trade-off between required adjustments, environmental benefits, and costs, making industry and business hesitant due to unclear benefits and high initial expenses. Also, these transformations are unique to each business model or configuration of reusable packaging systems (RPS), as are their economic and environmental performances. Consequently, the Life Cycle Assessment (LCA) and CBM literature on reuse has called for holistic approaches to this complex socio-technical system that can effectively support decision-making toward more feasible and sustainable pathways.

Although literature exists on influential factors to reuse CBMs, there is still a need of seeing how these can play a role in practice. This study adopts a system perspective to analyse the real-world involvement and influence of factors within value chain actors' decision-making processes, aiming to identify pathways for achieving life cycle environmental and economic success in reuse. A mixed methods approach is used, involving semi-structured interviews with stakeholders, followed by a focus group with industry experts. Hence, by means of a co-creation process, the data is analysed based on real-world applications of RPS, undercovering optimal decision-making configurations Furthermore, stakeholders' influence and involvement across the reusable packaging life cycle are traced. As a result, this exploration ; aims to set the foundation for developing an LCA-based decision-support tool, so practitioners (e.g., researchers and consultants) can constructively help industry stakeholders closing the implementation gap of reusable.

Life Cycle Assessment of shopping bags used in Portugal

João Guilherme Serra, **Paula Quinteiro**, **Ana Cláudia Dias**

University of Aveiro/CESAM - Centre for Environmental and Marine Studies

Shopping bags are used in society's daily activities, especially in the retail sector. However, production, use and disposal of shopping bags have come under increasing scrutiny due to their potential environmental impacts, contributing to the degradation of ecosystems, resource depletion and pollution. To address these issues, policies have been implemented in several countries, including Portugal, to reduce single-use plastic consumption and encourage the adoption of reusable plastic bags and bags produced with alternative materials, such as paper and textiles.

This study evaluates the environmental performance of 12 different shopping bags used in Portugal through the Life Cycle Assessment (LCA) methodology. The bags analysed cover single-use disposable high-density polyethylene (HDPE) bags and reusable options such as low-density polyethylene (LDPE), polypropylene (PP) (woven and non-woven), paper, cotton and jute bags. Environmental impacts were assessed using a cradle-to-grave approach. The results show that HDPE bags had the lowest environmental impact due to their lightweight design and low resource use during production. Among reusable plastic bags, LDPE bags with 100% recycled content demonstrated reduced impacts, highlighting the importance of recycled materials, whereas PP (woven and non-woven bags) required substantial reuse cycles to offset production impacts. For the alternative materials, cotton and jute bags had the biggest impacts due to resource-intensive cultivation and manufacturing, while paper bags performed best. The production stage

consistently accounted for the highest environmental burden, driven by resource and energy use, followed by end-of-life impacts from landfill leachate and incineration emissions. Sensitivity analysis revealed that end-of-life impacts reduce significantly as recycling rates of the bags increase. In conclusion, these results highlighted the potential for reusable bags to outperform single-use bags when used effectively, but to achieve optimal results, systemic improvements to recycling systems and consumer awareness about reuse are crucial.

Bridging innovation and circularity: Integration of low-TRL chemical recycling technologies into circular systems

Paula Milena Rincon Trujillo, Philip Biessey, Manfred Renner

Ruhr University Bochum, Germany

The transition from a linear to a sustainable circular economy requires the integration of innovative technologies that align with green chemistry principles and the sustainable development goals outlined in Agenda 2030. However, technologies are often evaluated individually, limiting the understanding of their potential impact on sustainability and circularity within a Circular System. This challenge is especially significant for low Technology Readiness Level (TRL) technologies, where data uncertainty is inherent due to their early-stage development. To address the challenges that arise from the integration of technologies, a framework that enables a holistic assessment of their influence on the overall performance of a Circular System is needed. Chemical recycling technologies are of particular interest in this context, as they play a crucial role in the closed-loop management of plastic materials and the advancement of circular economic principles.

The proposed conceptual framework evaluates different scale-up approaches for chemical recycling technologies by generating scenarios that reflect varying assumptions and operating conditions. A prospective life-cycle assessment (LCA) of these scenarios is conducted to analyze key sustainability and circularity indicators. The resulting data are then incorporated into a modular Circular System model, where technologies are represented as discrete modules. This structure enables the evaluation of system-level implications associated with disaggregating the system into technology-specific components, providing insights into how each technology may affect overall sustainability and circularity outcomes.

This knowledge-based conceptual framework offers a structured approach to support the integration of technologies into circular system models by systematically addressing uncertainties through scenario analysis, prospective life cycle assessment (LCA), and modular system modeling. Hence, this approach facilitates the transition to a sustainable circular economy by enabling data-driven, informed decision-making and fostering alignment with long-term sustainability goals.

Session 2.03: Advancing Polymer Recycling: Methods & Policy for a Sustainable Transition

Time: Thursday, 11/Sept/2025: 9:35am - 11:05am
Session Chair: Paola Federica Albizzati, Joint Research Centre - European Commission, Spain
Session Chair: Carlo Brondi, CNR, Italy

A market share-based model for the avoided burden approach of life cycle assessment considering future decarbonization in industries: A case of polymer recycling

Kazuma Hirata, Daiki Kata, Jun Nakatani

The University of Tokyo, Japan

In life cycle assessment (LCA) of the polymer recycling, estimation of avoided burdens influences the results of environmental benefits. Regarding types of materials and/or energy that are replaced by recycling or energy recovery, previous studies have implicitly assumed that primary materials or energy made from virgin fossil feedstock are replaced, but this assumption may be unrealistic in the future situation where resource defossilization is fully achieved. Without a method to determine which materials will be replaced by secondary materials based on the future market situation, a strategy for prioritizing polymer recycling technologies in the mid- to long-term would not be developed. In this study, we developed a novel model of the avoided burden approach of LCA using the market share of materials and energy relevant to secondary materials for taking the effect of the future decarbonization in industries on avoided burdens into account. The developed model was applied to a case study for recycling/recovery options of plastic packaging waste in Japan, and the differences between the conventional avoided burden approach and the developed model were presented. The results showed that, as decarbonization progressed in relevant industries, environmental benefits on the climate change impact were significantly influenced for chemical recycling (ammonia production) through gasification and energy recovery (solid fuel production and utilization) but slightly for mechanical recycling (pallet production). In addition, the sensitivity analysis to the decarbonization of grid electricity showed that it increased the net climate change impact for energy recovery because the avoided climate change impact intensity of steam generation would decrease. It was suggested that recycling/recovery options which could provide secondary materials or energy to industries whose production processes would have to rely on fossil-derived materials should be prioritized in the transition phase towards a decarbonized society.

Advancing Polymer Recycling: Integrating HydroPRT with Complementary Technologies

Stuart Coles[1], Matthew Ozoemena[1], Robert Heymer[1], You Wu[1], Geoff Brighty[2]

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The rapid expansion of the plastics industry has created significant environmental challenges, particularly at the end-of-life stage. Addressing these issues necessitates innovative approaches that integrate complementary recycling technologies. This study presents a Life Cycle Assessment (LCA) of the HydroPRT chemical recycling process, evaluating its integration with mechanical recycling and incineration with energy recovery. Using the ReCiPe 2016 impact assessment methodology and scenarios based on UK plastic waste streams, the study demonstrates that HydroPRT can achieve a 58.92% reduction in climate change

impacts compared to virgin plastic production, complementing mechanical recycling.

Three scenarios were modelled to assess environmental impacts under varying end-of-life management strategies: (1) incineration only, (2) mechanical recycling combined with incineration, and (3) an integrated approach combining HydroPRT, mechanical recycling, and incineration. Results indicate that Scenario 3 delivers the lowest impacts across 14 of 16 environmental categories, highlighting the importance of integrating advanced chemical recycling with other technologies to maximise environmental benefits and meet stringent EU targets, such as recycling 55% of plastic packaging waste by 2030.

The analysis highlights the critical role of policy frameworks in enabling infrastructure upgrades and aligning recycling technologies with regulatory targets. Sensitivity analysis reveals that enhancing collection and sorting rates significantly reduces environmental impacts, further reinforcing the necessity for system-wide improvements.

This study provides fresh insights into the complementarity of recycling technologies, offering a pathway for more sustainable polymer waste management. Future work should focus on refining data for collected plastic types, enabling the development of advanced sorting technologies and ensuring compliance with evolving regulatory requirements.

Quality of waste feedstock and quality of recyclate: zero burden or (how much?) avoided burden?

Steven De Meester

Ghent University, Belgium

Quality of resources is a crucial aspect in the circular economy and consequently should be taken into account in LCA, for example by the Circular Footprint Formula.

Starting point is the waste feedstock as resource. In general, we can take a zero burden approach and assign all impact to the primary production, or we can introduce an allocation factor to the waste as secondary resources. In plastics, it can be very pure PET collected by a deposit scheme. Or DKR350 mixed plastic waste. Should we differentiate the allocation between them?

Secondly, a plastic recyclate has a certain functional equivalence compared to virgin plastic. This Quality of Recycling determines its potential substitutability, depending on mechanical properties, aesthetic properties, safety and so on. Quantifying this avoided burden based on quality of the polymer/monomer and related market demand is crucial in circular plastics.

This presentation involves conceptual discussion of the two mentioned points, as well as giving potential practical solutions and examples, with focus on the discussion between mechanical and chemical recycling.

Quantifying the Environmental Costs of Phasing Out Legacy Substances for Plastics in Germany's Building and Infrastructure Sector

Sarah Schmidt[1], **Thomas Gibon**[2], **David Laner**[1]

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Plastics are the fastest-growing bulk material in the world. Meeting the increasing demand for plastics while achieving climate targets necessitates enhanced recycling within the plastics industry. Besides the packaging industry, the building and infrastructure (B&I) sector is one of the largest consumers of plastics. Strongly growing historic consumption and long product lifetimes in the sector limit the material availability for closing cycles. Moreover, the presence of so-called legacy contaminants, which have been used in production in the past, but are nowadays classified as substances of concern, poses a barrier for more effective recycling markets. In the present study, a high-resolution dynamic material and substance stock and flow model of plastics in Germany's B&I sector is integrated in a prospective life cycle assessment to evaluate potential trade-offs of phasing out legacy contaminants. Results indicate that annual plastic waste from B&I is anticipated to increase by more than 50% from 0.7 Mt in 2023 to 1.1 Mt in 2050. By 2100, end-of-life flows are projected to increase by a factor of 2.1 to 3.2 compared to 2023, depending on future plastic consumption trends. Without removing legacy contaminants during recycling, these substances are projected to remain above regulatory thresholds in end-of-life flows across all key applications except flooring until the end of the century. While restrictions on legacy contaminants in recycling products accelerate the contaminant phase-out, they also form a barrier to recycling and result in additional global warming impacts because of lower environmental benefits from recycling. However, it is also shown that innovative treatment pathways for contaminated plastic waste can partially mitigate the trade-offs linked to restrictions on contaminants in recycled plastics. The study forms an example on how integrated LCA modeling frameworks can be used to identify environmentally optimal plastic waste management strategies and provide robust support for policy and decision-making.

Effect of Feedstock Modelling and Multiple Loops of Polymer Recycling in environmental profile calculation

Giovanni Dotelli

Politecnico di Milano, Italy

Feedstock modeling involves quantitatively assessing material flows, chemical composition, and degradation behavior to optimize the recycling of diverse waste streams. Modeling tools and tracking protocols, including material flow analysis (MFA), are increasingly utilized to predict allocation or the behavior of feedstocks during recycling phases. These methodologies enable tailoring recycling processes to accommodate complex feedstocks, such as mixed polymers or contaminated materials, thereby enhancing material recovery and quality.

Multiple-loop recycling strategies extend material lifespans by incorporating closed- and open-loop systems. Closed-loop recycling focuses on preserving material properties for identical applications, while open-loop systems transform feedstocks into alternative products. Advanced techniques, such as chemical depolymerization and solvent-based purification, are key enablers for such approaches, allowing the recovery of monomers and oligomers from degraded or mixed materials.

On the one hand, technical challenges arise regarding feedstock storage, the nature of specific contaminants, and their influence on the associated recycling processes. These factors directly impact the performance and quality of materials in subsequent lifecycle stages. For instance, contamination levels significantly affect polymers' purity and mechanical properties during recycling.

Conversely, challenges also pertain to tracking and allocating recycled polymers across multiple product

lifecycles, ensuring transparency and consistency in material flow management.

European initiatives like the Circular Economy Action Plan actively support these advancements. Efforts include integrating feedstock modeling with life cycle assessment (LCA) tools to quantify the environmental benefits of multiple-loop recycling and developing harmonized standards for assessing recycled material quality. Pilot projects across the EU demonstrate the scalability of these systems in sectors such as plastics, textiles, and electronics.

Integrating feedstock modeling with multiple recycling loops offers a scientifically robust pathway to achieving resource efficiency, fostering circularity, and reducing environmental impacts in alignment with EU sustainability goals.

How to integrate market and policy instruments like mass balance fuel use excluded into the LCA of recycled materials?

Maximilian Menche, Christian Krüger

BASF SE, Germany

Since the launch of the EU's European Green Deal in 2019, a growing number of companies aim for net zero greenhouse gas emissions and circularity ambitions by or before 2050. Achieving these goals requires the reinvention of processes and step-change in technology development to accelerate the reduction of emissions. In addition, the recycling of post-consumer and pre-consumer plastic waste is an essential building block for the transition to a circular and net zero economy. Respective recycling technologies are relevant for enhancing resource efficiency, protection of oceans, mitigation of climate crisis effects, and strengthening the resilience of the industry by lowering the dependence on fossil resources.

Currently, circularity is mainly driven by mechanical recycling and there is still a long way to go to reach full circularity as we have globally a recycling rate of 8% only. Therefore, there is an urgent need to push new technologies like chemical recycling. For these value chains besides the recycling operation chemical processes are involved to generate recycled materials. To enable circularity and therefore accelerate the circularity journey new market-based instruments like the mass balance approach are needed. In the EU policy context, a new mass balance method is discussed, where the fuel along the processes needs to be deducted: Mass Balance Fuel Use Excluded.

This presentation will discuss the implications of mass balance methodologies, their integration in chemical recycling, and the consequences for LCA implementation.

Polymer Recycling and Life Cycle Assessment: An Overview of End-of-Life Allocation Approaches and Their Implications

Maria Evgenia Papavasileiou, Wouter van Kootwijk

Ecomatters, The Netherlands

Background

Sustainable polymer recycling requires robust Life Cycle Assessment (LCA) methodologies and supportive policies. A key challenge is determining how to allocate the environmental impacts of recycling between the primary life cycle (waste producer) and the secondary life cycle (recycled material user). This session explores various methodological approaches for allocation in polymer recycling and examines their implications

for LCA practitioners and the polymer industry.

Methods

Three primary allocation approaches are evaluated:

1. Cut-off approach: Assigns recycling benefits entirely to the secondary life cycle, encouraging the use of recycled materials.
2. Avoided burden approach: Attributes recycling benefits to the primary system, incentivizing end-of-life recyclin
3. Circular Footprint Formula (CFF): Employed in the European Commission's PEF methods, it flexibly distributes impacts based on market supply-demand balance expressed via "A-factor" values.

For the demarcation of the end of the recycling process, which is essential for harmonised impact allocation, we include the connection to the Waste Framework Directive and industry standards (e.g., EN15804, Together for Sustainability).

Main results

Using insight from a case study, we showcase the differences and implications of each approach for the polymer industry. The cut-off approach supports recycled material use, while the avoided burden approach rewards primary systems for recycling. The CFF allows dynamic adaptation to market conditions. Thereafter, we discuss where and how these methodological approaches are connected to (polymer) sector-specific policies and regulations.

Conclusions

Choosing an end-of-life allocation approach in polymer recycling significantly influences LCA outcomes. By aligning methodological strategies with market realities, regulatory guidance, and sectoral standards, stakeholders can achieve more meaningful environmental assessments, ultimately driving the transition towards sustainable polymer recycling.

European Initiatives supporting Assessing Environmental Impact of Polymers in Recycling and Life Cycle Contexts

Carlo Brondi, Matteo Cordara

CNR, Italy

Polymers are essential in various industries, but their extensive use raises environmental and health concerns, particularly due to persistence, microplastic formation, and potential toxicity. The European Union (EU) has implemented several initiatives to systematically assess and mitigate these impacts, focusing on polymer recycling and life cycle management as part of the European Green Deal and Circular Economy Action Plan.

Recent updates to the Registration, Evaluation, Authorisation, and Restriction of Chemicals (REACH) regulation introduced specific frameworks for evaluating polymers of concern (PoC). These include criteria for persistence, bioaccumulation, and toxicity (PBT), as well as testing strategies tailored to polymer-specific attributes like molecular weight distribution and solubility. Simultaneously, the EU Strategy for Plastics in a Circular Economy prioritizes the development of recyclable and biodegradable polymers, alongside reducing single-use plastics and microplastic emissions, emphasizing a life cycle perspective.

Scientific advancements under initiatives like Horizon Europe refine methodologies for assessing polymer impacts. Key research focuses include environmental fate modeling, advanced analytical methods for understanding polymer degradation and microplastic behavior, and in vitro/in silico toxicity testing to reduce reliance on animal studies. Furthermore, harmonized life cycle assessment (LCA) methodologies are being established to evaluate environmental impacts across polymer lifecycles, particularly end-of-life scenarios like recycling and biodegradation. The European Commission has launched the Environmental Footprint

methods to enhance the comparability of LCA applied to products and organizations.

Collaborative platforms such as the European Chemicals Agency (ECHA) Polymer Task Force foster stakeholder engagement and data sharing to address gaps in understanding long-term microplastic and nanoplastic behavior. These initiatives integrate scientific insights and policy to support evidence-based decision-making.

The EU's comprehensive strategy reflects its commitment to fostering sustainable polymer innovation, ensuring robust life cycle and recycling-focused impact assessments to protect environmental and human health.

Modeling WEEE Recycling with Life Cycle Assessment: the case study of an Italian Treatment Plant

Federico Iorio Esposito[1], Alessandro Salvi[1], Giovanni Dotelli[1], Paola Gallo Stampino[1], Laura Borghi[2], Martina Scoponi[2]

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WEEE recycling presents unique challenges and opportunities, as these materials combine valuable resources such as rare metals with hazardous components that demand specialized management to minimize risks to the environment and human health. Despite progress, Italy only collected approximately 360000 tonnes of WEEE in 2022 – far from the European target of 65% - due to factors such as insufficient regulations and limited public awareness.

This study investigates the environmental impact of recycling Waste Electrical and Electronic Equipment (WEEE) through a Life Cycle Assessment (LCA) of an Italian plant recovering plastics and metals through mechanical recycling to produce End-of-Waste (EoW) polymers. Recovered polymers—primarily, ABS and PS (flakes and pellets) and PP/PE —were evaluated using a cradle-to-gate LCA approach and a mass allocation, with SimaPro and the EcoInvent 3.9.1 database, in compliance to ISO 14040 standard. A cut-off approach treated incoming waste as burden-free, with impacts assessed through the EU-recommended Environmental Footprint 3.1 method.

Results revealed significant environmental benefits for recycled polymers compared to their virgin counterparts. ABS Flakes and PS Flakes showed a GWP of 1528 kg CO2-eq while Pellets showed slightly higher impacts due to the extrusion process. PP/PE showed the lowest impact at 1342 kg CO2-eq. Compared with up-to-date virgin processes from the database, ABS and PS Pellet showed an average reduction of more than 50% in GWP.

Sensitivity analyses showed that the plant's efficient processes are mostly impacted by waste disposal, and further gains are possible by recycling residual waste. Switching to a fully renewable energy mix further reduced environmental impacts. Finally to compare the impacts, an economic allocation was also performed.

These findings highlight WEEE recycling as a key pathway for reducing emissions, conserving resources, and advancing circular economy.

Acknowledgments: This study was carried out within the MICS (Made in Italy – Circular and Sustainable) project.

Session 2.04: Methodologies and Tools for Sustainable Agriculture and Food Value Chains Part I

Time: Thursday, 11/Sept/2025: 9:35am - 11:05am
Session Chair: Andrea Di Maria, University of Liege, Belgium
Session Chair: Olubukola Olumuyiwa Tokede, Deakin University, Australia, Australia

Socioeconomic impacts of increased legumes production for human consumption in Norway

Rannva Danielsen[1], Clara Valente[1], Anna Birgitte Milford[2], Simen Wilsher-Lohre[2]

[1]NORSUS, Norway; [2]NIBIO, Norway

A dietary shift towards less red meat and more plant-based food, including legumes, is healthier and more climate-friendly. We assess the socioeconomic effects of increasing the production and consumption of legumes in the Norwegian diet, primarily by assessing the direct employment impacts of a shift in production and consumption from livestock to legumes. We also assess the impact on GHG emissions from such a shift. To do so, we create three different scenarios, all of which have increased legumes production: 1) Maximising employment in the agricultural sector and cultural landscapes, 2) Minimising GHG emissions from production, and 3) Even reduction of all livestock. For each scenario the calorie intake for the Norwegian population was held constant, i.e., when the production (and consumption) of legumes increases, we assume an equivalent reduction in the consumption (and therefore production) of animal products so that calorie intake is the same in every scenario. Our results show that 1) sheep and cattle production is very labour-intensive and legumes production is very labour-efficient, 2) minimising GHG emissions from production and an even reduction in livestock production both have a drastic impact on direct employment in the agricultural sector and would reduce full-time equivalent employment by approx. 7000-7500 positions (nearly 30% of agricultural employment), and 3) minimising GHG emissions from production would reduce GHG emissions by an estimated 1500 tonnes Co2-equivalents annually and an even reduction in livestock would reduce emissions by 1400 tonnes CO2-equivalents annually. We conclude that a drastic shift towards a plant-based, low-emissions diet in the Norwegian population would reduce emissions from food production considerably but would also have a severe impact on direct employment in the agricultural sector, which may disproportionately affect the districts of Norway where agricultural production is an important source of employment.

Combining qualitative and quantitative social life cycle assessment to analyze protein supply chain in Sweden

Edoardo Desiderio, Karin Östergren

RISE Research Institutes of Sweden, Sweden

Despite their environmental advantages over conventional meat, legume-based proteins must also be backed by socially responsible supply chains. Social impacts—both upstream and downstream—can undermine their overall contribution to sustainability. This study applies Social Life Cycle Assessment (S-LCA) to Sweden's emerging pea-protein supply chain, highlighting risks and opportunities across key stakeholder groups: Farmers, Workers, Local Communities, and Society.

Using a mixed-method approach, we combined stakeholder surveys with social risk modeling. A bottom-up qualitative assessment was conducted with Swedish farmers and processing workers, complemented by a cradle-to-factory-gate S-LCA using the PSILCA 2.0 database in OpenLCA. Scenario comparisons were

made between Sweden, Germany, Canada, and China.

Results reveal moderate but improvable social performance in Sweden, particularly related to financial security, economic support, and working hours for farmers. Upstream supply chain risks were identified in areas such as child labor, migration flows, and social security expenditures, particularly linked to the import of fertilizers and pesticides. China showed high risks in safety measures and youth illiteracy indicators.

The study demonstrates the value of integrating real-time stakeholder insight with social risk databases to evaluate people-centered sustainability in emerging supply chains. It offers a replicable framework for assessing social risks in plant-based food systems and supports companies and policymakers in developing socially responsible scaling strategies. Future research will explore the integration of MCDA to analyze trade-offs across sustainability dimensions.

The Biodiversity Footprinting for Agricultural Transition (BFAT) project: for an improved modelling of the impact of agricultural production on biodiversity

Eliette Verdier[1], Alexis Burguburu[1], Eugène Pipraud[1], Arthur Albaz[1], Théo Joly[1], Amandine Kemmel[2], Juliette Alnikine[2], Magdalena Czyrnek-Delêtre[1], Guillaume Neveux[1]

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Our planet is currently facing a significant loss of biodiversity. This decline is particularly concerning for the functioning of ecosystems, especially agricultural lands, which cover more than one-third of the Earth's terrestrial surface. Agriculture is a major contributor to the drivers of biodiversity loss such as pollution, land use (soil erosion, simplification of landscapes) and land use change. As a result, it is crucial to address the threats that agriculture poses to biodiversity urgently.

Many tools and methodologies were developed to quantify biodiversity loss due to agriculture. However, none of these tools can differentiate the impact on biodiversity resulting from various agricultural practices. To provide a better framework for decision making in agricultural transition, there is a need for a meaningful integration of agricultural practices into global biodiversity impact assessment methodologies.

The Biodiversity Footprinting for Agricultural Transition (BFAT) project aims at enabling economic actors implementing agroecological practices in their operationss and/or supply chain to demonstrate their reduced biodiversity impact. It adresses three main tasks: (1) aggregate knowledge on agroecological practices, (2) provide methodological approaches to reward best practices and (3) provide impact factors tailored to specific agricultural practices, including low-impact practices.

BFAT will deliver results at various levels, covering the key agricultural commodities based on their production geography. These results will include a list of practices with their related environmental exchanges (elementary flows), refined midpoint impacts categorized by geography and production mode, and the aggregated impacts on biodiversity (endpoints) through the different assessed pressures (land use and land use change, climate change, pollution), including landscape structures and soil health. Biodiversity impacts are measured with ecosystem extent condition metrics (such as MSA.km^2 or PDF.m^2). Depending on the methodology used for aggregating midpoints, results may also be time-integrated (in MSA.m^2.yr or PDF.m^2.yr).

Life Cycle Sustainability Assessment to evaluate the sustainability of food value chains in developing countries: a case study of maize flour in Chad

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The agri-food sector is crucial for food security and economic development, especially in countries such as Chad, located in the central part of the African continent, where maize flour is a staple food and a key value chain for livelihoods. However, maize production and processing face significant sustainability challenges due to low adoption of sustainable resource management, inadequate infrastructure, and governance issues. This has led to stagnant productivity, to which producers have responded by increasing the cultivated areas, instead of focusing on improving yields. Addressing these challenges requires comprehensive assessment tools to inform policymakers and promote sustainable practices across the value chain. Within the EC/INTPA project "Value Chain for Development" (VCA4D), this study applies a Life Cycle Sustainability Assessment (LCSA) framework to evaluate the environmental, economic, and social performance of the maize flour value chain in Chad. Data were collected through several field missions, stakeholder interviews, and then combined with secondary data from Ecoinvent and PSILCA databases.

Preliminary environmental results show that most carbon emissions come from fertilizer use and diesel-powered generators. This is largely because most agricultural and processing areas outside the capital lack access to the national electric grid. Additionally, indoor maize flour cooking using charcoal poses serious health risks from air pollutants. Economically, the value chain shows low profitability for smallholder farmers due to high costs and market inefficiencies. Milling and transport expenses dominate, while market access remain limited. Socially, key risks include low wages, child labor, and poor occupational health, with gender disparities persisting. However, women-led cooperatives have emerged to improve conditions and support resilience.

The study highlights the need for resource-efficient agricultural practices, optimized transformation processes, and improved social safeguards. By integrating environmental, economic, and social assessments, the LCSA framework offers insights to guide stakeholders toward sustainable, resilient maize flour value chain in Chad.

Embedding Sustainability in Product Development: A Pathway to Global Targets

Ileana Manera[1], Ondina Rocca[2]

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Integrating sustainability early in product development is crucial for transforming a company's product portfolio and achieving global sustainability goals.

While many companies recognize the importance of sustainable innovation for long-term competitiveness and reputation, they often struggle to translate sustainability strategies into practical actions. Some companies are beginning to incorporate sustainability dimensions into their product portfolios, which can effectively communicate the sustainability performance of products both internally and externally, and accelerate the development of more sustainable solutions.

Key process steps such as idea generation, concept development, recipe formulation, and ingredient sourcing have been identified as critical areas where eco-design tools and sustainability methodologies can be applied to achieve better results.

This presentation will highlight several tools, known as Sustainability Simulators, developed to support the product innovation process at the idea generation and recipe development stages. These simulators provide practical tools for Product Recipe Developers to define the sustainability positioning of new product concepts and for R&D teams to test ingredients and origin scenarios using nutritional and sustainability

markers. This helps in selecting the best raw materials for the development and reformulation of new products.

The collaboration between sustainability and product development teams enables the identification of opportunities and quick wins, as well as better and more transparent communication about a product's sustainability attributes to consumers, retailers, and other stakeholders.

Food Impacts Toolkit: Delivering Information on Environmental Impacts of Foods to Consumers

Marius Rödder, Talita Amado, Paul Appel

corsus - corporate sustainability GmbH, Germany

Food production is one of the main contributors of anthropogenic environmental impacts, particularly through agriculture's role in pushing several planetary boundaries. Agriculture drives most impacts (80% and above each) related to land use change, biodiversity loss, global freshwater use, and nutrient pollution. It is estimated to contribute around 25 % to anthropogenic climate change.

Consumer choice can make a significant difference in reducing these impacts: along with the reduction of food waste across all parts of the value chain, dietary change is one of the major levers for reducing diets' footprint. To make more environmentally friendly choices, consumers and meal providers require information about the environmental impacts of food. This data, however, is often missing.

To provide the information in an accessible and flexible way, we created a freely available, open-source API tool called Food Impacts Toolkit (FIT). While the current tool uses generic data (e.g. French Agribalyse database), product-specific data can be added. Currently a prototype, FIT calculates impact scores for individual products as well as recipes and delivers the data in a flexible way, so that it can be displayed for different user groups. The tool features a method for deriving proxy datasets by adapting regional datasets to estimate environmental impact values in different geographies with minimal data. We discuss the main aspects of the tools' methodology, as well as its possible use cases, strengths and current limitations.

Session 2.05: Regional Sustainability via Life Cycle Instruments Part I

Time: Thursday, 11/Sept/2025: 9:35am - 11:05am
Session Chair: Takunda Yeukai Chitaka, University of Bordeaux, France
Session Chair: Pia Wiche, EcoEd, Chile

A methodology for assessing the sustainability of hydrogen valleys

Marco Serafini[1], Fabiana Romano[2], Alessandro Arrigoni[1], Eveline Weidner[1], Mariagiovvanna Minutillo[3]

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Hydrogen valleys are emerging as a key component of regional sustainable development strategies, offering a pathway to decarbonize industries, transport, and energy systems. However, their sustainable implementation requires a comprehensive understanding of environmental, social, and economic impacts throughout their life cycle.

Like industrial clusters, hydrogen valleys involve integrating multiple industries and activities, creating complex systems with interconnected environmental impacts. Currently, no dedicated guidelines are available for addressing the multiple end-use and, therefore, different functions, of hydrogen valleys. This work proposes a methodology tailored to hydrogen valleys to assess the environmental life cycle impacts, enabling regional stakeholders to better understand the sustainability implications of hydrogen valley development. The proposed methodology is built upon a review of existing life cycle assessment (LCA) studies on hydrogen production, transportation, and utilization with a focus on regional development and on LCAs of industrial clusters.

By applying this methodology, regional stakeholders can prioritize areas for improvement and develop targeted strategies to minimize environmental impacts, ultimately supporting the transition towards more sustainable and resilient regional development pathways.

Use of life cycle management to support regional sustainable development - experiences of selected European regions”

Fritz Balkau[1], Guido Sonnemann[2], Takunda Chitaka[2]

[1]sustainable solutions, France; [2]University of Bordeaux

Regional administrations have become major players in enhancing sustainability at their level. However, their operational effectiveness is often limited due to the still common focus on ‘single-issue’ actions that lack a life cycle and multi-SDG perspective. To better understand how, and to what extent, life cycle thinking presently informs regional sustainability initiatives, the recent EU Interreg project LCA4Regions, with regional partners from Finland, Italy, Lithuania, Poland, Portugal, Slovenia and Spain, examined how they use life cycle approaches such as life cycle assessment (LCA) to help address priority issues in resource efficiency, circular economy, and sustainable public procurement. The study documented over 100 useful applications of life cycle methods in both assessment and life cycle management (LCM). While some regional actions employed officially accepted methods (e.g. for carbon footprint), there was also widespread recourse to non-standard terminology and non-quantified methods. In general, little consideration was given to the life cycle dimension of regions’ various sustainability actions. Even insightful LCA studies did not always lead to action due to a disconnect between academic researchers and public policy officials. Conversely, regional administrators proactively employed LCM actions such as eco-design, labelling, purchasing etc. even without recourse to a preceding LCA as this is widely regarded as complicated and onerous. The project

suggested several follow-up actions to address the above-mentioned issues. (216 words)

Environmentally performant bio-economy supply chains from Macauba in Brazil requires proper management of the by-product pulp oil: A consequential LCA

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Macaúba, a native palm of Brazilian tropical forests, is highly productive per hectare and resilient to adverse conditions, often planted on degraded land. Its fruit contains oil concentrated in both the pulp and kernel. While the kernel has high-value applications, such as in pharmaceuticals, the pulp remains underutilized, primarily directed towards soap production or discarded as waste. This study analyses the environmental consequences of alternatives to enhance the use of Macaúba pulp oil in higher-value markets by consequential Life Cycle Analysis (LCA). Four scenarios are considered: (i) soap production substituting conventional soap; (ii) biodiesel through enzymatic transesterification; (iii) jet fuel via hydrotreatment (HEFA); (iv) oil refining substituting for vegetable cooking oils and fat.

EcoInvent background data were combined with experimental foreground data from previous research, adopting a functional unit (FU) of 1kg of crude Macaúba pulp oil to be managed. The Environmental Footprint (EF 3.1) Life Cycle Impact Assessment method was used across 9 categories. The preliminary results show the reference as competitive with net negative impact for all assessed impact categories. Regarding biodiesel, it is performant concerning climate, especially if "conventional" biodiesel from soybean (BR) is avoided. Important difference between soybean and fossil diesel is noted, as in several categories, fossil will lead to a net induced (positive) impact. For aviation, there is a tendency for being neutral. Refining process presents an option with benefits, although it is less competitive compared to soap production and conditional upon energy recovery from the residue (spent bleaching earth). For majority of impacts, the use of ethanol derived from sugarcane (BR) and, for global warming potential, the enzyme, could be optimized to reduce the environmental impact of the biodiesel production process. These findings, along with insights on performance dependency will be confirmed within next stages of the work through uncertainty and sensitivity analysis.

Mapping the Climate Profiles for the Decarbonization of Italian District Heating and Cooling Networks

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District Heating and Cooling Networks (DHCNs) are increasingly regarded as pivotal solutions for decarbonizing the building sector, particularly in alignment with the European Union's ambitious long-term sustainability goals. These centralized energy systems facilitate the delivery of heating and cooling at a district scale, playing a critical role in reducing emissions. Their application is especially pertinent in the context of Italy's historical city centers, where stringent cultural heritage and landscape preservation regulations limit intervention strategies. A holistic environmental assessment of DHCNs necessitates a Life Cycle Assessment (LCA) framework capable of addressing their comprehensive environmental burdens beyond greenhouse gas emissions alone. To the authors' knowledge, no studies to date have systematically analyzed the variation in the climate profile of DHCNs at a national level in Italy.

This study introduces a national-scale climate profile mapping based on a universally applicable LCA-driven decision-support model for DHCNs. The model employs a cradle-to-cradle life cycle approach in accor-

dance with European standards, enabling a detailed evaluation of environmental impacts across all system components and auxiliary elements. Input data for the analysis were obtained through a statistically significant mapping of existing networks across Italy, facilitated by the Italian District Heating Association (AIRU). The findings reveal that each network has its own distinct climate profile, primarily influenced by the local utilization of energy resources. This mapping, combined with precise network positioning data, provides a foundation for developing tailored decarbonization strategies. Moreover, it establishes benchmark climate profiles that can be utilized both at the regional scale and by network typology, offering a valuable tool for assessing and guiding the transition to low-carbon district energy systems.

Farm-scale and regional-scale use of renewable energy to replace diesel fuel

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Global agriculture heavily relies on fossil resources. The FARMfuture projects explore how agriculture could function without these resources, focusing on replacing diesel with renewable energy using existing technology in Schleswig-Holstein, Germany.

We addressed two main questions: what would the energy system look like for an individual farm, and what would it look like for the entire region? In both cases, we aimed for an autonomous energy system to avoid the fluctuating prices that can occur during high energy consumption periods, like harvesting, which could lead to unstable food prices.

For the farm context, we modeled a typical crop rotation in a North German cash crop production system. Using literature data, we estimated the energy consumption for all field work, including tillage, plowing, and harvesting. We then calculated the minimum energy storage required to supply renewable energy during peak times and determined the minimum area needed for photovoltaic (PV) energy to recharge the storage between these peaks.

For the regional context, we took a similar approach but modeled the share of the twelve most common crops in terms of area use, covering > 97% of the total agricultural area. Our key finding was that the regional energy model required significantly less energy storage per hectare than the farm model. This is due to greater variability and less pronounced peaks in energy consumption, as multiple crops interact in the regional model. Additionally, energy-intensive activities like harvesting or plowing are spread out over a longer period regionally than on a single farm.

This suggests that the infrastructure demand for renewable energy use, including production and storage, should be shared among users with diverse energy needs. Monoculture or highly homogeneous regions will use this infrastructure less efficiently, leading to a higher demand per hectare for energy production and storage.

Supporting Regional Sustainability Goals: Comparative LCA of Vacation Rentals and Hotels

Giulio Maria Mercatali[1], Didier Beloin Saint-Pierre[2], Roland Hischier[2], Giorgio Baldinelli[1], Jacopo Sorani[2]

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The rapid spread of Vacation Rentals (VR) listings in tourist destinations is raising concerns about their displacement effects on residents, businesses and their environmental sustainability. While some VR platforms claim their services reduce the carbon footprint of the hospitality sector, regional representatives and researchers have limited data to validate such statements. They also lack knowledge on the potential sustainability trade-offs between VR and Hotels . Furthermore, the environmental impacts of induced extra income for apartment owners have not been consistently investigated . We thus conduct a comparative Life Cycle Assessment (LCA) between VR accommodations and hotels in the region of Florence to inform regional decision makers.

The functional unit for this comparison is "the lodging needs for one overnight stay of one guest in an accommodation". The assessment uses annual operational data to offer average impact values that account for change in occupancy rates and seasonal energy demand. The system boundary includes the: building of accommodation, hospitality activities, energy and water consumption, waste management, guest transportation and renovations. Our study is based on primary data for resource use, while energy use, water consumption, and waste generation are based on min-max scenarios over the year.

Our work highlights important trade-off for the VR. Indeed, they are often linked with lower impacts from pre-existing buildings and higher energy use due to larger surfaces, inconsistent thermal management, and inefficient cleaning practices. Conversely, hotels are burdened by significant embedded impacts from large construction, but demonstrate higher operational efficiencies because of optimized energy systems and standardized practices. Transportation impacts further differentiate the systems since VR are dispersed and hotels can more easily leverage public transports. Other than further understanding the trade-offs between the two systems, this study offers further information for local administrators to decide on the most beneficial lodging options to meet their sustainability targets.

Drinking Water Scarcity: Man-Made Pollutants in the Potomac River Basin, USA

Veronica M_Ngaling Tangiri

Prince William Soil and Water Conservation District, Virginia, USA.

Prince William Soil and Water Conservation District, United States of America

Drinking water scarcity is a growing concern. Over 2 billion people live in countries experiencing high water stress, and about 4 billion people experience severe water scarcity during at least one month of the year. This is predicted to increase with climate change (UN, 2019).

The Potomac River Basin covers 14,670 square miles. It includes the District of Columbia, Maryland, Pennsylvania, Virginia, and West Virginia, with a population of over 6.89 million, increasing at 13% per decade (2020, US Census). Drinking good water is a human daily need, but there are persistent challenges due to increasing development.

Urban runoff pollutants like road deicers, sediments, fertilizers, and nutrients impact water quality. Wastewater treatment effluents with high concentrations of salts (sodium) from food and pharmaceuticals are discharged into streams/rivers, which are also drinking water sources. All these have a significant impact on human health and aquatic ecosystems. There are no drinking water standards for sodium. State and federal agencies recommend that sodium levels in water not exceed 20 milligrams per liter (mg/L) for people on very low sodium diets, and 270 mg/L for moderately restricted sodium diets. Water quality monitoring

records have shown over 2,500mg/L of salt in streams discharging into drinking water sources. The increasing use of road slats makes the situation scarier.

Prince William Soil and Water Conservation District (PWSWCD) in Virginia is a local state agency working with the community to promote water quality awareness through citizen science. Its Water Program encourages water sustainability and science data in the Potomac River Watershed.

This work examines runoff pollutants (salts) as a water scarcity challenge for future generations. It also relates to per- and polyfluoroalkyl substances (PFAS), which need more water quality awareness for regional sustainable drinking water.

Environmental Impact of Upper Cisokan Pumped Hydro Energy Storage in Indonesia's Energy Transition

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This study presents a cradle-to-gate Life Cycle Assessment (LCA) of the Upper Cisokan Pumped Storage (UCPS) project, Indonesia's first pumped hydro energy storage facility. It evaluates the environmental impacts of the project from material extraction to operation, using primary data from detailed project reports and secondary data from the Ecoinvent v3.8 database. The assessment covers seven environmental impact categories, including human health, ecosystem quality, and resource use. The operational phase, largely due to electricity use for water pumping, dominates most impact categories. However, the construction phase has a greater influence on Global Warming Potential (GWP) at 200 g CO_2-eq/kWh, Cumulative Energy Demand (CED), and Fine Particulate Matter Formation (FPMF). Land use and mineral resource scarcity are also primarily affected by construction, given the intensive use of concrete and steel. Emissions from the reservoir surface contribute around 1.9% of total project greenhouse gas emissions, further highlighting the importance of careful planning and environmental monitoring.

Scenario analysis indicates that shifting to renewable electricity could reduce GHG emissions by up to 88%, especially under a 100% renewable scenario. Enhancing round-trip efficiency from 74.5% to 85% also leads to notable reductions across all impact categories, improving overall sustainability. In contrast, extending the project's operational lifetime from 60 to 100 years shows minimal effect on environmental impacts per kilowatt-hour, although it improves long-term infrastructure value. Overall, the findings highlight the UCPS project's strong potential to aid Indonesia's energy transition, aligning with national strategies outlined in the RUEN (National Energy General Plan) and RUPTL (Electricity Supply Business Plan), while emphasising opportunities for further environmental optimisation.

Life Cycle Assessment of Wastewater Treatment in Small Tourist Areas of the Baltic Sea Region to Support Regional Sustainability: Insights from the NURSECOAST-II Project

Jolanta Dvarioniene[1], Dalia Gedgaudiene[1], Dziugas Dvarionas[1], Ksawery Kuligowski[2], Izabela Konkol[2], Marta Pluciennik[3], Virpi Vorne[4], Anu Reinikainen[5], Morten Lykkegaard Christensen[6], Janis Zviedris[7], Frans Silvenius[5]

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The NURSECOAST-II project took on the considerable challenge of conducting research in the field of wastewater management in small tourist areas along the Baltic Sea coast. It applied various methods of domestic wastewater treatment and used a life cycle approach to assess their environmental impact, with the goal of contributing to the sustainable development of the region. After conducting research on a small wastewater installation in the Baltic Sea region, the findings highlight that small treatment plants are often undocumented, their environmental impact underestimated, and regulations vary widely.

Life cycle assessment (LCA) can help state and local authorities create a sustainable water resources management system. The LCA performed in this study will not only support local authorities in identifying gaps in wastewater management but also assist in improving national water resource management strategies and reducing nutrient pollution. Once local authorities, owners of the wastewater treatment plant (WWTP) implement pilot wastewater treatment projects, regional authorities considering both the efficiency of wastewater treatment and the environmental impact assessment using the life cycle approach may set laws and incentives that make the potential replication of such investments in other local regions possible. Additionally, the LCA results will be compared with traditional wastewater treatment approaches to make these solutions transferable to other regions or countries. They will also be used to spatially quantify the nutrient reductions to the Baltic Sea using GIS tools. The LCA studies will be presented not only to local authorities to improve local policies, but also shared with various stakeholders, such as regional associations and policymakers, to enhance national water resource management policies.

This work was supported by the NURSECOAST-II project "Model Nutrients Reduction Solutions In Near-Coast Touristic Areas" (Nr #C015) co-funded by the European Union by the INTERREG Baltic Sea Region Programme 2021–2027.

Session 2.06: Nutritional LCA for Sustainable Agri-Food Management Part I

Time: Thursday, 11/Sept/2025: 9:35am - 11:05am
Session Chair: Silvia Zingale, Agroscope, Switzerland
Session Chair: Gianluca De Nardi, EcorNaturaSì Spa, Italy

Future of Protein: A Global LCA Model for Optimizing Land Use and Integrating Renewable Energy in Single Cell Protein Hybrid Farm

Vishal Khanpit[1,3], **S Viswanathan**[2], **Olaf Hinrichsen**[3]

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Global food production and food supply chains are major CO2 emitters, contributing around 26% of anthropogenic GHG emissions. Additionally, population growth and dietary shifts exacerbate environmental burdens. To prevent serious and irreversible effects of climate change, there is an urgent need to find potential future foods that emit less CO2 during production. Microalgae shows great potential, but it faces criticism for high energy use, which triggers indirect GHG emissions. This study addresses the following key questions about microalgae as a sustainable future food.

1. Can microalgae production meet the global demand for protein while ensuring sufficient land availability without compromising global commitments to achieving net-zero emissions?
2. How do novel renewable energy sources impact CO2 fixation and reduce land use for microalgae-based protein production?
3. Which country/region is most effective to grow microalgae in terms land use and CO2 emission?

In this study, we propose a Life Cycle Assessment (LCA) and linear optimization-based hybrid farm model for microalgae based protein (MA-P) production that optimizes land use for cultivation, harvesting, protein processing, and integrated renewable energy generation (solar, agrivoltaics, floating solar, offshore wind, onshore wind). This model, applicable globally and at the country level, also assesses the CO2 fixation potential of MA-P, identifying optimal regions for production using conventional grid electricity. Our findings suggest that MA-P could satisfy global protein needs using only 0.032% of available land—far less than the 26.95% required for animal-based protein. It predicts that each land unit could yield 28 times more protein than soybean farming and 2.1 times more than a solar-only microalgae farm. This hybrid farm model could significantly enhance food security, resilience, and environmental sustainability worldwide.

Global Biodiversity Footprints of Agricultural Production Systems: Comparing the Biodiversity Impacts of Staple and Luxury Food Crops

Michael Götz, **René Itten**

Zurich University of Applied Sciences, Switzerland

According to the FAO (2024), more than a third of the world's land area is used for agriculture in 2022. Total cropland area grew by 80 million hectares since 2001 (+ 5 %). Major cropland area expansion could be observed in Africa, South America, and Southeast Asia. The global increase in cropland area since 2001 can be attributed primarily to the expansion of temporary crops, such as wheat, rice, and maize (+ 110 million hectares or + 10 %). The area under permanent crops, like oil palm, coffee, and cocoa, was expanded by 55

million hectares, which represents a relative increase of 40 % since 2001.

Considerable shares of agricultural land expansion, especially for permanent crops like coffee, cocoa, and palm oil, are located in highly sensitive ecoregions with high biodiversity. The biodiversity impact of intensified agricultural land use in these regions could lead to rapid degradation of these ecosystems.

As part of a multi-year research project, a case study is being developed to assess the environmental impacts of different agricultural production systems. To this end, regionalized environmental and biodiversity impact characterisation factors are combined with crop-specific land use and productivity data.

The aim of this project is to integrate statistical and remote sensing based data in the Life Cycle Inventory modelling of the different agricultural products as well as to compare the global impact of staple food crops like wheat, maize, and rice to luxury foods like coffee and cocoa.

The crops assessed in this case study include coffee, cocoa, soy, palm oil, wheat, rice, maize, and sugar cane. The selection of crops was based on their relevance, particularly in terms of land use and global production volume, and on the commodities to be covered by the European Union Deforestation Regulation EUDR (European Commission, 2024).

Life Cycle Assessment of novel protein sources uses a newly developed protein-quality-based approach

Andreas Geß[1], Özlem Özmutlu[2], Tullia Tedeschi[3], Sara Cutroneo[3], Barbara Prandi[3]

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Alternative proteins derived from plants, microorganisms, and insects present sustainable solutions to meet the nutritional needs of a growing population while mitigating environmental impacts, particularly by replacing meat. However, their functional properties, such as solubility and gelation, are influenced by extraction techniques and large-scale processing, posing significant challenges. The ProxIMed project investigates both innovative and traditional raw materials to enhance these proteins, addressing consumer acceptance and cultural or religious considerations to develop appealing, sustainable food products tailored to Mediterranean markets. The project emphasizes ecological benefits by incorporating life cycle assessments (LCA) from the outset. ProxIMed evaluates 11 protein sources—tomato pomace, tomato leaves, lentils, sesame cake, date by-products, microalgae, mycoprotein, insects, faba beans, chia seeds, and mallow leaves. These sources are processed into protein powders and integrated into established food products, such as meat alternatives, ready-made meals, and yogurt. As the project is aiming to create more sustainable food systems, a design for the environment approach is applied for all food products and their corresponding value chains and production processes. To that purpose a LCA is accompanying the development phase. As the products are intended to be alternatives for established protein foods like egg or meat, a comparison shall be done with the industry standard LCA of these established foods. However, plant-based proteins are often not as easy to uptake by the human body as animal-based proteins. McAuliffe et al. (2022) proposed a method for incorporating protein quality into the concept of nutritional LCA, using the Digestible Indispensable Amino Acid Score (DIAAS) to enable a standardized comparison of protein uptake from various sources. The DIAAS score is not only available for novel foods, so their approach is modified using the amino acid score. This presentation shows the first results of the newly developed protein products.

Beyond carbon emissions: assessing environmental impacts of traditional Norwegian meals

Fabiana Frota de Albuquerque Landi, Rannvá Danielsen, Erik Svanes

NORSUS Norwegian Institute for Sustainability Research, Norway

The environmental impact of food has been extensively analyzed and published. The focus has been on food products and whole diets, while meals seem to have received less attention. However, most food is consumed in the form of meals. Traditional dishes are often made from local ingredients and reflect part of the identity of regions, thus addressing important cultural aspects. This study uses Life Cycle Assessment (LCA) methodology to evaluate the environmental impacts of traditional Norwegian dishes. The calculations are expressed in global warming potential, freshwater eutrophication, marine eutrophication, terrestrial acidification, water use, and land use. Results are compared to a vegetarian stew and three popular international meals. Greenhouse gas emissions ranged in an order of 14 times according to the meal, with meat content, water content, and portion size as key drivers. On average, traditional dishes showed environmental profiles comparable to other Nordic meat-based diets using local ingredients. Reducing meat content proved to be the most effective way to lower impacts, while sourcing locally had less influence. Yet, maximizing the use of all parts of the animal and reusing leftovers reflects a conscious low-waste mentality. As the nutritional content is not the same for all dishes, the environmental impacts cannot be directly compared. Future work will explore other nutritional functional units to capture the role of each dish in a complete diet.

A sustainable and healthy bite: A nutritional life cycle assessment of mealworms compared to conventional protein-rich food

Zhengxuan Wu[1], Elena Werner[2], Daniel Maga[1], Venkat Aryan[1]

[1]Fraunhofer UMSICHT, Germany; [2]Alpha-Protein GmbH, Germany

As global demand for sustainable protein sources intensifies, mealworms are emerging as a viable alternative protein source due to their high nutrient density and low environmental impact. This study explores the environmental and nutritional performance of large-scale mealworm production in Germany, where access to primary production data remains limited.

Utilizing the Nutrient Rich Foods (NRF) 9.3 index, this research includes nine recommended nutrients into the functional unit and considers three nutrients to be limited as a separate measure. In considering mealworm as an alternative protein source, protein quality is also included in the NRF 9.3 index using the Digestible Indispensable Amino Acid Score (DIAAS). To evaluate environmental impacts, the study employs the EF3.1 Life Cycle Impact Assessment (LCIA) methodology. This research also provides a comparative assessment, examining mealworm production alongside traditional animal-based protein rich foods, including meats cheese and eggs, as well as four plant-based protein rich foods.

The results demonstrate that mealworms perform favorably compared to conventional animal-based foods in most of impact categories relevant to food, yielding an 80 times lower nutrition adjusted overall environmental impacts than beef and 11 times lower than chicken, while contributing clearly less to the intake of the nutrients to be limited. The analysis further highlights that defatting mealworm before consumption enhances their nutrient profile, as the saturated fat is considered as a nutrient to be limited. However, the findings also indicate that protein pea and soybean maintain a more favorable environmental impact profile overall, showing up to 67% less impact than mealworms. Given that this study does not account for nutrient bioavailability, which is an essential factor that can influence the comparative nutritional value, further studies including the bioavailability is needed to refine the understanding of the nutritional advantages of plant-based foods.

Automated Life Cycle Assessment of Food Assortments including Planetary Boundaries, Multi-Nutrients and Health Outcomes: a novel Approach for Food Retail, Wholesale and Gastronomy

Toni Meier, Frank Forner, Susann Schade

Institute for Sustainable Agriculture and Food Economics • INL, Germany

While food systems have become more efficient and technologically advanced in recent decades, sustaining healthy diets within environmental limits remains a key challenge. Today, menu planners, procurement officers and end consumers are faced with hundreds to thousands of foods in retail & wholesale markets, often pre-processed and labeled with mandatory and voluntary information. Unfortunately, the extent of different brands, labels, stores and marketing strategies does not help to make sustainable decisions but rather leads to increased confusion at point of sale. In particular, assortment software applications used in food retail, wholesale and food service still lack sustainability indicators (such as GHG, water use, PEF, PHC [1]), hindering a broad implementation in daily business decisions and, thus, alignment with sustainability goals.

For these reasons, we have developed a monitoring and optimisation framework in R, allowing an automated LCA of multiple food items (mono- & polyproducts). While mono-products (single-ingredient foods such as a raw apple, carrot or olive oil) can be easily accounted for, poly-products (foods containing several ingredients such as pre-processed tomato sauce or a pizza) cannot be accounted for, as the recipe is not known. To overcome this challenge, a mathematical method comprising 32 steps was coded in R (based on [2]), conducting a full nutritional and environmental analysis per food item. The approach, developed using a dataset of 1,800 foods across various categories, is now applied in several pilot projects comprising >40,000 single foods used for menu planning (in healthcare, business & hospitality catering).

[1] Meier T et al. (2024). Bridging Nutritional and Environmental Sustainability within Planetary Boundaries in Food LCAs: SWOT review and development of the Planet Health Conformity Index. Sustainability (MDPI), 16(23), 10658

[2] Bohn K et al. (2022): Estimating food ingredient compositions based on mandatory product labeling. In: Journal of Food Composition and Analysis, 110, 104508. Elsevier

Session 2.07: Mass Balance Chain of Custody and LCA methodology and practices

Time: Thursday, 11/Sept/2025: 11:30am - 1:00pm
Session Chair: Markus Berger, University of Twente, The Netherlands
Session Chair: Guy Castelan, PlasticsEurope, Belgium

Allowing the certification of PCFs for mass balanced products

Stefan Gaertner[1], Jana Gerta Backes[1], Patrick Ober[2], Stefan Majer[3]

[1]Meo Carbon Solutions GmbH; [2]ISCC System GmbH; [3]DBFZ GmbH

This presentation discusses how mass balance (MB) schemes can be aligned with LCA standards to allow a comparable and reproducible calculation of product carbon footprints (PCF) for MB products.

We describe the challenges arising from the perspective of the leading certification system ISCC (International Sustainability and Carbon Certification). ISCC PLUS is a scheme to trace non-conventional raw materials through supply chains for different Chain of Custody models. The ISCC PLUS MB approach is widely adopted in industries co-processing non-conventional with fossil feedstock. Further, ISCC is currently introducing its carbon footprint certification (CFC) module to further specify rules and guidance of existing standards for PCF calculations.

A main challenge for the alignment of MB and LCA arises from the fact that MB systems attribute sustainability characteristics to dedicated product volumes. Hence, MB-based emission allocation approaches need to distribute or allocate emissions to product batches, while ensuring that the accounting of the overall emission inventory remains with ISO 14040/44/67. Additional complexity arises for multi-input-systems with different attribution possibilities from input to output and their alignment with existing LCA standards. These standards often lack regulation for mass-balanced systems. The process to develop a full ISO standard on LCA of MB products is just in progress and will eventually last another couple of years. Therefore, ISCC aims to introduce additional requirements to allow a comparable and reproducible PCF calculation for MB and ISCC PLUS certified products under ISCC CFC.

We will give an introduction into the concept of MB and describe challenges for the development of a PCF approach for MB products. In addition, we will introduce our approach for a PCF certification of MB products to align common MB regulations with LCA standards. The combination of MB and PCF certification will be described with concrete product examples.

Mass balancing in current verification and critical review practice – Challenges and outlook from an inter-industry view

Max Rehberger, Daniel Müller, Jonas Johannisson

TÜV SÜD Product Service GmbH, Germany

The use of mass balancing approaches in LCA is highly disputed. While Ecoplatform / EPD see it very critical and have thus stopped accepting mass balanced materials completely many industry-led initiatives such as Catena-X, Low emission steel standard (LESS) and Together for Sustainability (TfS) define additional criteria to be met. Single industry player have started defining own approaches for bridging the supply chain footprint of single materials such as steel and final product LCA modelling of complex industrial products. LCA ISO Standards in the current versions do not reflect this aspect sufficiently and may be interpreted as well as rather restrictive.

This misalignment in practice leads to challenges in constellations where companies source from different

industries and regions from tier n down to the final end product and strive for a meaningful third party assessment.

Critical review and verification practice is highly challenged by the fact that no uniform acceptance criteria exist. A lot of hope can be put into new standards being developed such as ISO/DIS 13662 or ISO/AWI 14077 and discussions in the revision of e.g. ISO 14067.

We give an insight into practical challenges different industries are facing and an update on the status quo how testing inspection and certification companies are coping with this. Also considering upcoming regulatory challenges where mass balance will play a role.

Transformation of the steel industry

Julian Suer, Nils Jäger

thyssenkrupp Steel Europe AG, Germany

The production of quality flat steel products is commonly linked to highly integrated sites, which include hot metal generation via the blast furnace route, basic oxygen steelmaking, continuous casting, and subsequent hot-rolling. In order to reach near zero emission steel production a shift away from traditional carbon-based metallurgy is required.

Coal-based blast furnaces can be replaced by direct reduction plants combined with electric melting units. In a direct reduction plant iron ores can be reduced by hydrogen and the product, the direct reduced iron (DRI), can be melted and processed to hot metal in an electric melting unit. The resulting hot metal has the same characteristics as the product from the blast furnace with the difference that much less carbon was required for its production. The hot metal can be further refined to crude steel in a steel plant and subsequently processed to hot-rolled coil as is common practice today.

Typical integrated steel sites include several blast furnaces. The produced hot metal is filled into torpedo cars and is transported to the steel plant. In the steel plant hot metal from different blast furnaces is mixed due to logistical reasons. As most steel producers will decarbonize over time, blast furnaces will gradually be phased out of service. When the first blast furnace is replaced by a DRI plant and an electric melting unit, the question rises if the high-emission and low-emission hot metal should be mixed or not and how these routes are to be evaluated from an LCA perspective.

A practical example from the steel industry is used to explain how the combined further processing of high-emission and low-emission products can work. Both, decoupled and mixed driving modes are illustrated, and the effects are analysed from an LCA and mass-balance approach.

Exploration of Chain of Custody and Mass Balance principles and their impact on plastics sustainability

Chloé CANO-AMEVET, Virginie RENAVANT, Amandine LOUISE, Florence DELANGE

Schneider Electric, France

To increase knowledge on traceability and evidence of the origin of materials used by Schneider Electric, a study has been conducted on third-party certifications for recycled and bio-based plastics. Understanding Chain of Custody (CoC) is seen as essential to take on transparency and accountability in the supply chain, as it serves as a framework to verify product sustainability claims. This presentation will delve into the principles of CoC and the distinct nature of the Mass Balance (MB) model, particularly in the context of recycled and bio-based plastics sourcing.

The differences between Mass Balance rolling average and Mass Balance credits allocation will be explored, with a focus on how these mechanisms function in sustainable sourcing. In the plastic compounds

industry, credit allocation can be applied to both material and energy flows. However, the lack of standardized allocation rules presents significant challenges. Currently, renewable energy credits are sometimes specifically allocated to sustainable materials, creating disparities across various processing technologies and potentially skewing the perceived environmental value of these materials.

Supported by Schneider Electric transparency program on environmental data, enhancing the ability to perform accurate Environmental Material Value comparisons in Life Cycle Assessment (LCA) is an objective of this study. The complexities of Chains of Custody and Mass Balance principles will be addressed to achieve a deeper understanding of their impact on environmental claims and the importance of establishing standardized practices for equitable evaluation. This presentation aims to highlight these critical issues and to provide insights into their implications for sustainability assessments and decision-making in the plastics industry.

Electricity and the chain of custody

Tomas Ekvall[1], Natalia Lopez Marin[2], Yulia Liu[3], Ellen Riise[4], Stefano Zuin[2]

[1]Tomas Ekvall Research, Review & Assessment (TERRA); [2]Electrolux; [3]Chalmers University of Technology; [4]Essity

Mass balance and book-and-claim are important examples of chain-of-custody approaches. The mass-balance approaches include the rolling average: an average over a period is used to represent the product characteristics (e.g., recycled or bio-based content) of a physical flow where the actual content varies with time. Another mass-balance approach is the credit method, where a single physical flow is divided into parts that are assigned different characteristics. In a book-and-claim system the product characteristics are traded separately from the physical flows through certificates.

The current debate on mass-balance and book-and-claim approaches in life cycle assessment (LCA) can benefit from previous debates on location-based and market-based modelling of electricity. Location-based electricity is the annual average for a specific region. It corresponds to the rolling-average mass-balance approach, because the actual electricity mix varies from hour to hour. Market-based electricity accounts for Guarantees of Origin and other contractual instruments. It corresponds to the credit mass-balance approach or the book-and-claim approach, depending on whether the contractual instrument requires a physical grid connection.

The Environmental Footprint framework and the international standard for product carbon footprints (ISO 14067) stipulate market-based modelling. The standard on greenhouse gas (GHG) emissions from organizations (ISO 14064-1) stipulates location-based modelling and allows for the market-based approach to develop additional information, but does not specify how the additional information can be used. The Scope 2 Guidance of the GHG Protocol requires that companies present both market-based and location-based results, when they have any operations in an electricity system with contractual instruments.

Market-based electricity modelling can stimulate the expansion of renewable-energy production, but risk leading to greenwashing and double counting of renewable electricity. The consequences depend on details in the rules for market-based electricity. We discuss these challenges and give recommendations on how the standards can be harmonized.

Development of PCR Open Standard Guidance for Including Mass Balance Chain of Custody into LCAs and EPDs

C. Jason Pierce[1], **Poonam Khatri**[2]

[1]*Eastman, USA;* [2]*USDA Forest Service, Forest Products Laboratory, USA*

Credit-based mass balance chain of custody has been utilized across multiple industries for decades but is currently experiencing significant growth in application for circular and bioeconomy solutions. However, there is lack of standard methodological guidance for how to approach credit-based mass balance in LCAs and EPDs.

The American Center for Life Cycle Assessment (ACLCA) operates a PCR Open Standard to provide recommended guidance and support harmonization across PCR program operators. In 2024, ACLCA launched a working group to develop a mass balance addendum to the ACLCA Open PCR Standard. The primary goal of the ACLCA mass balance addendum is to develop first-of-its-kind guidelines for practitioners on how to approach credit-based mass balance when performing LCA modeling and in reporting results via EPDs. Recommendations will be made to PCR program operators for how to address product systems involving a credit-based mass balance. Such guidance, if implemented correctly, could enable organizations in value chains to claim environmental benefits of using materials with specified sustainability characteristics.

A secondary goal is to develop LCA and EPD guidelines for the other chain of custody models as defined in ISO 22095. This talk will summarize the results, successes, and challenges in the development of this seminal PCR guidance.

The increasing impact of bio-attributed products in reducing Greenhouse Gas Emissions

Christian Krüger, **Peter Saling**, **Ivana Krkljus**

BASF, Germany

Renewable raw materials, as regenerative biobased feedstock for chemicals, have an enormous potential for reducing feedstock-related greenhouse gas emissions. Dedicated to driving the growth of bioeconomy, we continuously explore and develop building blocks for turning the bioeconomy ambition into a reality. Bio-based products are already available in the market but are limited in growth due to lack of technologies and product development costs. Alternatively, scale up and utilization of biobased feedstocks, leveraging existing infrastructure, requires utilization of different chain-of-custody models. That's how a growing need for bio-attributed products, which provide the same quality and performance of their conventional equivalent and a proven benefit determined by the reduction of the Product Carbon Footprint in cradle-to-gate assessments, can be fulfilled. Ranging from a discussion around collaboration to drive sustainability in the chemical industry, toward current and future policy asks, we discuss about the opportunities of using different types of feedstocks and how we can accelerate industry transformation strategies by using attribution models, model biogenic CO2-uptake in a meaningful, fair, and transparent way, based on accepted and harmonized standards, such as global ISO standards. We provide reference points and statistics and address the latest and the most important bioeconomy related aspects of bio-attribution as science is evolving.

Methodology of mass balance model applicable to industrial materials

Taichi Suzuki[1,2], Ichiro Daigo[2]

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There has been a growing demand for products emphasizing environmental attributes based on the life cycle thinking. Recently, mass balance model, one of the Chain of Custody models, has been applied to the environmental claims of industrial materials such as plastics and metals. Under the mass balance model, disproportional allocation of the specific characteristic within a target material is possible, provided that the total mass of the specific characteristic within input to and output from the specific process is balanced. However, some challenges remain in applying mass balance model to industrial materials. For example, no common definition of mass balance model applied to industrial materials exists, resulting in lacking credibility among stakeholders and raising concerns about deceptive environmental claims.

This study aims to define the requirement and limitation for applying mass balance model to industrial materials. Mass balance model involves a discrepancy between the physical flow and the informational flow associated with the specific characteristic, whereas these flows align in the conventional approach based on proportional allocation. However, coinciding with these flows may require additional assets, e.g., a dedicated plant for input having the specific characteristic, which may cause an additional environmental burden. In the transition phase to a sustainable society, this discrepancy could occur only if the additional burden is avoided by introducing an accounting system such as mass balance model. Therefore, we set environmental or economic rationality as the primary requirement when applying mass balance model. In addition, when the disproportional allocation of the specific characteristic is applied to industrial materials under mass balance model, the allocation should not be unrealistic. Here, the limitation for mass balance model is that only claims within the technically feasible range are possible. Our methodology covers the requirement and limitation when applying mass balance model to industrial materials.

Session 2.08: Policy Coherence: Tools and best practices for an efficient and effective sustainable transition

Time: Thursday, 11/Sept/2025: 11:30am - 1:00pm
Session Chair: LAURA GARCIA HERRERO, EC - JRC, Italy
Session Chair: Martina Orefice, Joint Research Centre, Italy

Enhancing circularity of e-mobility through life-cycle thinking – the example of the JRC scientific support for the end-of-life vehicles EU policy

Martina Orefice[1], Nacef Tazi[1], Thibaut Maury[1], Umberto Eynard[1], Daniele Candelaresi[2], Silvia Bobba[1], Fabrice Mathieux[1]

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Electric mobility (e-mobility) is a key driver for the green transition and climate neutrality goals. Nonetheless, value chain of e-vehicles, in particular of e-motors, are still barely circular. E-motors are rich in copper and, usually, in rare earths: all critical raw materials (CRMs) lost at end-of-life as the e-motors are shred with the car bulk to only recover ferrous materials.

Circular management of products goes beyond end-of-life management and to be effective needs to be life-cycle based. This is the approach of recent EU policies for e-mobility such as the vehicles regulation proposal, (VRP) 2023/0284/EC , and the batteries regulation, (EU) 2023/1542. Simultaneously to the VRP, in July 2023 , the JRC published a study which explored measures for e-motors circularity, targeting as manufacturers as waste management operators, and all translated as Articles of the VRP. A 2025 JRC study explores the implementation of these Articles, assesses further circularity strategies and ensures alignment with other CRMs-related policies, e.g. the CRM Act.

Building on the implementation of the batteries regulation, a first-of-a-kind life-cycle based regulation, JRC embraced a life-cycle thinking approach to analyse and improve e-motors circularity. Beyond mapping the whole value chain and collecting primary data, JRC applied an effective and operational life-cycle approach by establishing the dialogue with stakeholders in a way that upstream players would benefit of a measure developed as a win-win compromise with downstream players and vice-versa. For instance, labelling and information request requirements were developed to ease dismantling and sorting operations at the end-of-life while protecting the confidentiality of manufacturers' information.

This contribution aims at showing the benefits of life-cycle thinking in tackling e-vehicles circularity and in developing measures to benefit simultaneously upstream and downstream players of the value chain and, hence, as a broader result benefit the society in compliance with the goals of life-cycle management.

Enhancing Product Comparability: Frameworks for Meaningful Decision-Making in Life Cycle Management

William Lepercq[1], Emmanuel Logakis[2], Benjamin Canaguier[1], Massimo Muzzi[2], Alessandro Bottarelli[2]

[1]Schneider Electric; [2]ABB

Informed product comparison is essential for guiding customers toward sustainable choices. This research explores two complementary solutions for enhancing comparability in life cycle management.

The first approach maximizes the use of Environmental Product Declarations (EPDs) in alignment with ISO 14025. It involves prioritizing comparability requirements, assessing feasibility, and estimating levels of

comparability based on adherence to these requirements.

The second approach addresses cases where EPDs lack sufficient comparability, e.g., due to using different LCIA databases. It proposes defining priority physical attributes—such as recycled content, recyclability, durability, and absence of hazardous substances— according to EN/ISO standards. Life Cycle Assessments (LCA) are of paramount importance in selecting the right attributes representing the most significant environmental burdens/hotspots. However, limitations are highlighted, particularly the reduced systemic assessment of product impacts on ecosystems and resources compared to full LCA data.

The study also establishes overarching principles for product comparison: adopting a life cycle perspective, multi-criteria assessment, proportionality to focus on significant environmental aspects, and alignment with frameworks like the European Sustainable Product Regulation, ISO 14021, and the EU Green Claims Directive.

This framework empowers customers with meaningful comparisons while advancing the integration of life cycle thinking into sustainable product decision-making.

The Environmental Footprint: science-based life cycle assessment methods for informed policy making

Laura Garcia Herrero[1], Mauro Cordella[2], Valeria De Laurentiis[1], Giulia Listorti[1], Susanna Andreasi Bassi[1], Nicola Ferrara[1], Esther Sanye Mengual[1], Fulvio Ardente[1]

[1]European Commission, Joint Research Centre (JRC), Ispra, Italy; [2]European Commission, Directorate General Environment (DG ENV), Brussels, Belgium

The use of the Environmental Footprint (EF) methods1 have been recommended by the European Commission as a harmonized approach for assessing the environmental performance of products and organizations. As life cycle assessment (LCA) methods, the EF aim to provide a comprehensive and science-based framework for evaluating the environmental impacts of human activities. The method's validity, reliability, and acceptance are underpinned by a continuous multi-stakeholder consultation process, bringing together experts from industry, academia, NGOs, and government institutions.

Through a collaborative effort, the EF methods have undergone rigorous development and refinement, incorporating the latest methodological advancements while at the same time addressing stakeholders needs. As a result, the EF methods have become a robust and accepted tool for environmental assessment, enabling decision-makers (including policymakers) to make informed choices and drive sustainable development. This is reflected in their wide use over the last 20 years. The EF methods today encompass a broad range of environmental impact categories, including climate change, resource depletion, among others.

As EF methods are in continuous development, adapting to emerging policy priorities and stakeholder needs, stakeholder engagement is crucial to ensure their relevance and effectiveness. By maintaining an open dialogue, the EF methods can address specific concerns, incorporate new insights, and reflect changing societal values. Examples include incorporating a biodiversity impact indicator or integrating biogenic carbon accounting, but also exploring possible insights by non-LCA methods, as well as shifting to the user perspective by analyzing sustainability product labels to improve the communication of results.

This contribution will present the most recent EF developments, their current status and the way forward, with a focus on the collaborative efforts that underpin the process.

Assessing supply risks in the bio-economy via a newly developed criticality framework and tool

Dieuwertje Louise Schrijvers[1], Naeem Adibi[1], Thomas Schaubroeck[2], Milena Amaral[3], Eduardo Entrena[4], Tomas Rydberg[5]

[1]WeLOOP, France; [2]Luxembourg Institute of Science and Technology (LIST), Luxembourg; [3]Neovili, France; [4]Contactica, Spain; [5]IVL Swedish Environmental Research Institute, Sweden

The EU-funded CALIMERO project aims to develop a harmonized methodology for assessing the sustainability of bio-based products and processes. Recognizing the criticality of raw materials as a vital aspect of the economic pillar of sustainability, the project integrates considerations of environmental and social risks into the sustainability assessment framework. For this, a new framework for assessing supply risks in the bio-economy is proposed.

Building on earlier efforts, the IRTC project (International Round Table on Materials Criticality), funded by EIT RawMaterials, proposed a model to assess and mitigate criticality, focusing on quantifiable indicators for minerals and metals. Similarly, the BIRD method, developed by TU Berlin, addresses supply risks for bio-based raw materials, categorizing criticality indicators by "type" (e.g., socio-economic, environmental, or technical). The IRTC model, in contrast, links indicators to company risks such as accessibility, price volatility, and reputation impacts.

In CALIMERO, the IRTC and BIRD frameworks are combined to create a comprehensive approach to assessing supply risks in the bio-economy from a company perspective. This integration is demonstrated through an illustrative case study in the construction sector, focusing on a Spanish wood panel producer. Indicators relevant to the bio-economy, derived from the BIRD framework and recent advancements, are aligned with the IRTC model. Using a newly developed data collection and assessment tool, key inventory flows are analyzed, providing actionable insights into raw material criticality.

The project formulates recommendations to enhance criticality awareness and mitigation in the bio-economy, addressing identified data gaps. Additionally, it outlines pathways for future research to further integrate criticality into the Life Cycle Sustainability Assessment (LCSA) framework, ensuring a robust evaluation of sustainability across economic, environmental, and social dimensions.

Product Environmental Footprint Category Rules (PEFCR) for Hotel Accommodation Services

Elia Rillo[1], Ugo Pretato[1], Bianca Maria Raffaelli[1], Marc-Andree Wolf[2], Kirana Wolf[2], Susanne Lein[3], Jan Christian Polania Giese[3], Isell Baldauf[3], Julia Olliges[3], Marie Audren[4], Marta Machado[4]

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The European Commission developed the Environmental Footprint (EF) method as a reliable way of measuring the environmental performance of products (PEF) and organisations (OEF) over their entire life cycle. The PEF method envisages the development of PEFCRs as specific set of rules for individual product categories. PEFCRs help practitioners focus on the relevant aspects of the considered good or service and increase reproducibility of PEF studies.

The present project is developing a PEFCR for Hotel Accommodation services, to be applied by the European hotel industry. The development of the PEFCR is led by a Technical Secretariat including industry representatives (hotel chains, hotels, hotel association), EF experts, an environmental NGO, and the European Commission.

While all other PEFCRs have been developed for goods, the PEFCR for Hotel Accommodation will be the first for a service. We will present and discuss important insights, and needs for adjustment to the PEF method when applied to services, moreover location-specific ones such as for hotels.

The final PEFCR will enable hotels to calculate the specific impacts per room type. The environmental pro-

file of each room type may be used both internally, to evaluate possible improvement actions, and for external communication, such as sustainability reporting, and enables hotel guests to compare results among hotels. The project started in October 2023 and the PEFCR is expected to be published before the end of 2026. During the first year of the project, the Representative Product PEF study was carried out, which supported the development of the first draft PEFCR. The first draft PEFCR will undergo a public consultation in the first quarter of 2025. Supporting studies testing the implementability of the PEFCR will be carried out from mid of 2025; we will hence be able to present further learnings of the already advanced method.

TransZeroWaste project: Decision support tool providing LCA, LCC and Circularity Indicators to support the transition towards green steel

Maura Camerin[1], Sébastien Zinck[1], Laurent Chion[1], Jérémy Ludwig[1], Diego Penaranda[1], Marie-Sophie Roderich[1], Tiago Silva[2], Helena Monteiro[2], Martin Hubrich[3]

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Steelmaking is a major source of global industrial CO2 emissions, making it a critical sector for decarbonization in order to achieve the EU's plan of carbon neutrality by 2050. A key pathway toward this goal is the transition to hydrogen-based steel production, requiring substantial changes to existing production units and huge investments. This shift is expected to impact recycling processes, as demand for high-quality direct-reduced iron (DRI) pellets and high-quality scrap will increase, creating new challenges around raw material availability and introducing novel by-products.

While various methodologies exist for Life Cycle Assessment (LCA) in materials production, there is currently no integrated tool designed specifically for steelmaking allowing dynamic and interactive assessments, enabling users to adjust key parameters and view corresponding environmental impacts and estimated economic outlays.

The 'TransZeroWaste' Horizon Europe project aims to develop a comprehensive tool that integrates environmental performances (LCA), Life Cycle Costing (LCC) and Circularity Indicators (CIs) for steel production. The tool will compare multiple scenarios, evaluating performance before and after the transition to hydrogen-based steelmaking of the involved partners, focusing on the energy demand and by-product quality. A methodology linking different types of indicators will be investigated, foreseeing the application of Multi Criteria Decision Analysis (MCDA) and Planetary Boundaries (PB) framework between LCA, LCC and CIs results.

The tool will be developed with the support of industrial partners, ensuring that both functionality and design align with users' needs and industrial requirements.

The resulting software will serve as a decision support tool, allowing steelmakers to assess the performance of their industrial production system, including the tracking of progress towards EU's carbon-neutrality targets. By consolidating key features within a single interface, the tool will facilitate a comprehensive evaluation of steel production's environmental, economic, and circularity performances. This will support informed data-driven decisions in steel industry's transition towards sustainability.

Experiences Applying the (Product) Environmental Footprint (PEF) Method and connection to Existing and Upcoming European Legislation and Policy

Wouter van Kootwijk, Freya Goffart De Roeck, Max Sonnen

Ecomatters, The Netherlands

Life cycle assessment (LCA) is a well-established methodology for holistic product environmental performance measurement. To unify LCA practices in the EU, the European Commission adopted the Recommendation on the use of Environmental Footprint (EF) methods in 2021, following over a decade of development. The Product Environmental Footprint (PEF) method aims to harmonize approaches and ensure environmental footprints are universally comparable against industry benchmarks or other products.

The EF method ensures credible footprints by imposing strict requirements on process, content, format, and quality. To streamline EF studies, industry associations are developing Product Environmental Footprint Category Rules (PEFCRs), which largely standardize the LCA process and data needs for product groups. Having been involved in the development, review, and implementation of PEFCRs, Ecomatters will share its experiences and lessons learned.

The EF method's value in policy contexts is increasingly recognized by EU regulators. While the Recommendation to use EF methods is currently not mandatory, it is referenced in existing and upcoming EU legislation and policies, such as:

- The Corporate Sustainability Reporting Directive (CSRD), where EF methods are recommended for calculating and reporting environmental impact.

- Sustainable product design, green public procurement criteria, and communication requirements under the Ecodesign for Sustainable Products Regulation (ESPR).

- Specific rules for substantiating green claims, building on EF methods.

- Development of labelling systems like the EU Ecolabel, incorporating durability, recyclability, and recycled content.

- The forthcoming EU environmental footprint database to enhance data availability and accessibility.

This session will address key developments, challenges, benefits, drawbacks, and lessons from practical implementations of EF methods for future-proof legislation and industry operations

Session 2.09: LCA in Policy: Frameworks, Compliance & Placement Part II

Time: Thursday, 11/Sept/2025: 11:30am - 1:00pm
Session Chair: Diego Iribarren, IMDEA Energy, Spain
Session Chair: Antonio Valente, ecoinvent, Switzerland

A Methodological Framework for the Ecodesign for Sustainable Products Regulation

Chiara Magrini, Vincenzo Senatore, Maria Gonzalez Torres, Judit Rodriguez Manotas

European Commission, Joint Research Centre (JRC-Seville), C. Inca Garcilaso, 3, 41092 Sevilla, Spain

The Ecodesign for Sustainable Products Regulation (ESPR) is central to the European Commission's initiative to promote environmentally sustainable products. It provides a structured approach to set ecodesign requirements, focusing on enhancing circularity, resource efficiency, energy performance, and other sustainability aspects across various product groups. In this context, the Joint Research Centre (JRC) of the European Commission has developed a robust scientific methodology aimed at evaluating products and contributing to the definition of requirements. This methodology is crucial for shaping policy options that encompass various sets of requirements with different ambition levels. Key elements of the methodology include a comprehensive assessment of life-cycle environmental impacts for each product group, identifying the most relevant circularity aspects and evaluating economic impacts throughout the product life cycle. Additionally, the methodology considers the implications of ESPR product requirements on the EU's open strategic autonomy, proposing mitigation strategies such as enhancing circularity and substitution where applicable.

A notable aspect of this methodology is the establishment of a method to develop classes of performance for circularity parameters, which could be used to define thresholds and/or affect consumer's choices through labels.

Furthermore, the method explores the interaction between the future ESPR label and other existing labels, such as the Energy label, the EU Ecolabel, and the Digital Product Passport (DPP), ensuring a cohesive labelling strategy.

The aim of this contribution is to present some aspects of the methodology to better integrate circularity into the product policy development according to the needs of the new regulation.

This comprehensive approach by the JRC not only facilitates the effective implementation of the ESPR but also supports the broader transition towards a more sustainable, resource-efficient, and circular economy within the European Union. The outcomes of this research will significantly influence future regulatory frameworks, promoting innovation and sustainability in product life cycles.

Toward the harmonisation of the environmental performance of plastic piping systems: the definition of complementary Product Category Rules for above- and below ground applications

Gioia Garavini[1], Alessandra Zamagni[1], Peter Sejersen[2]

[1]Ecoinnovazione, Italy; [2]TEPPFA, Belgium

The increasing market demand for Environmental Product Declarations (EPDs), particularly in the construction sector, has driven manufacturers to develop LCA studies aimed at obtaining EPD certification for their products. However, under the current requirements of EN15804+A2, there remains room for arbitrary choices when e.g., setting the functional unit and defining scenarios for life cycle stages that are not under the direct control of the manufacturer. This has led to varying methodological choices and assumptions, making the results of EPDs from different plastic piping system producers not fully comparable.

In response to these challenges, the European Plastic Pipes and Fittings Association (TEPPFA) the development of two European standards for Product Category Rules (c-PCRs) for plastic piping system outside building structure and inside buildings.

The main challenges include: i) reaching a common agreement on the definition of the functional and declared units to ensure comparability and identifying the main components to be included in a plastic piping system, considering that the configuration of these systems is highly project- and context-specific. ii) Defining common scenarios in cases where context specific data for the installation phase and end of life (EoL) are unavailable, and identifying the minimum processes to be considered for these life cycle stages.

The presentation will focus on detailing key elements of the approach taken, such as the definition of the functional and declared unit and the scenarios for installation and EoL, where different practices coexist at the European level. Those elements can ultimately provide a contribution in view of the the EU Construction Product Regulation.

Screening Product Environmental Footprint Analysis Applied to Fuel Cell and Hydrogen Systems

Claudio Carbone[1], Giuseppe Di Florio[1], Khaoula Ben Hnich[2], Sumanth K.R. Maddula[2,3], Diego Iribarren[2], Tarik Nawaya[4], Olga Bereketidou[5], Raphael Briere[6], Simone Maranghi[7], Alessandra Zamagni[7], Till Bachman[8], Davide Beretta[8], Giorgia Galvini[9], Alessandro Agostini[1]

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The Product Environmental Footprint Category Rules (PEFCRs) have been established for various product categories, like dairy products, apparel and footwear, hotel accommodation services and also batteries and accumulators. However, specific guidelines for Fuel Cell and Hydrogen (FCH) systems are urgently needed to foster a sustainable hydrogen economy in the frame of energy transition. The HyPEF project—Promoting an Environmentally-Responsible Hydrogen Economy by Enabling Product Environmental Footprint Studies—aims to develop and implement these specific PEFCRs, adhering to the methodological framework set forth in the Commission Recommendation (EU) 2021/2279.

As part of this initiative, hydrogen-specific product categorization has been conducted, leading to the identification of representative products within selected subcategories, that include 'electrochemical devices for hydrogen production,' 'compressed hydrogen storage tanks for heavy-duty mobility,' and 'hydrogen fuel cells for electricity generation.' This work presents the main findings from the screening of the Product Environmental Footprint (PEF) of these representative products. We provide an analysis of the criteria list, methodological specifications (such as system boundaries, multifunctionality approaches, and impact categories), and the environmental hotspots identified for FCH products. These results will set the ground for the inaugural PEFCRs for hydrogen systems. This research is part of the HyPEF project, which is supported

by the Clean Hydrogen Partnership and its members and funded by the European Union (Grant Agreement No. 101137575).

Do infrastructures matter? A spatial and temporal analysis of considering climate change life-cycle impacts of infrastructures. A focus on energy sector.

Romain Besseau, Anne Bouter, Alessandro Arrigoni, Nicolae Scarlat

European Commission Joint Research Centre

Life-cycle emissions related to infrastructures are often discarded from the life-cycle systems' boundaries. Some explanation could be their low overall contribution to the climate change impact given their extended lifetime combined with high outputs, especially in the energy sector before the current energy transition.

On the other hands, the development of emerging technologies alongside with weather-dependant aspects for renewables could bring forward a different picture. As of today, the emissions linked to the fuel combustion and its upstream emissions were largely dominating the total. However, this might change switching towards emerging and renewable energy sources. The risk is then to underestimate environmental performances of such technologies in the path forward to the energy transition.

This study aims to quantify the differences due to excluded infrastructures-related impacts in the energy sector. Relying on the ecoinvent database, we developed a dataset providing the infrastructures-related impacts per unit of power capacity installed. We additionally employed the premise Python library to generate prospective LCA values. ENTSO-E data were used to assess local load factors per energy type across European countries, enabling us to evaluate the impact per unit of energy produced.

This study will present a case study on the production of green hydrogen in Europe to showcase the above-mentioned work. By exploring the infrastructures-related impacts, and analysing its dependency to geographical, technological, or temporal parameters, this study will display the potential importance of including or not the infrastructures within the system boundary of emerging technologies.

Such findings could inform policymakers and industry stakeholders, highlighting the potential need for quantifying infrastructures environmental impacts or not depending on the perimeter of the study. This work could also support decision-making to ultimately decide whether or not infrastructures should be part of the quantified picture and when.

On the comparability and reproducibility of PEFCR

Paul Domberger, Ulrike Kirschnick

Technical University Leoben, Austria

The product environmental footprint (PEF) is an approach to harmonize the implementation of life cycle assessment (LCA) in the European Union. Based on PEF, product environmental footprint category rules (PEFCR) can be developed to improve the reproducibility and comparability of results for specific product groups. PEFCR compliant results are permitted to be used for comparative assertions between products within the product category. To create a PEFCR, a representative product (RP) is developed, that reflects the current state of the art of the product category. It can be a real or virtual product that is used to define the specific modelling rules and data quality requirements. The life cycle impact assessment (LCIA) results of the RP can be used as a benchmark for comparison per impact category or as normalized and weighted single score.

To compare LCIA results provided by two different entities, it must be ensured that differences stem from actual product differences and not from differently implemented modeling. This requires a complete and

transparent set of requirements in the PEFCR that is also applied to the RP model. The work at hand examines the reproducibility of the RP from the PEFCR for synthetic turf – sports applications, by remodeling it in openLCA using the EF 3.1 database and LCIA method. The goal is to assess whether the documentation in the PEFCR is sufficient to reproduce the results and to contextualize possible deviations. The initial attempt to remodel the RP shows a large difference compared to the benchmarking values due to partly unclear modelling instructions, insufficient database documentation and some user errors. The results also illustrate the limited interpretability of single score results in general. An iteration of the model shows significant improvements and several suggestions to improve the transparency of the PEFCR and the EF 3.1 database are derived.

Pursuing sustainability in the waters full of rules: an example of practising LCM in the Calanus product value chain in Norway.

Anastasia Henriksen, Annik Magerholm Fet

Norwegian University of Science and Technology, Norway

Developing new industries based on underutilized resources from the oceans, represents significant opportunities for both global food security and economic growth. One of the species that has been advocated for its potential is the plankton organism Calanus finmarchicus. Commercial fishing of Calanus in Norway was initiated in 2019, since then a limited fishing activity have been carried out. The Norwegian company Zooca has researched the opportunities and initiated production of human health supplements and animal feed based on this resource.

Zooca manages the production, marketing and sales of the products, while independent fishing companies operate the fishery. The results from an LCA-study of the Calanus product value chain reveal that the fishing phase generates the highest environmental impacts. Zooca has no direct influence on this part of the life cycle. This is a common challenge across marine resource-based industries. However, unlike companies that utilize commercial fish stocks and can select their fishing partners, Zooca has very few options for sourcing the raw materials.

This makes the company heavily dependent on fishery regulation to align for effective and sustainable harvesting. Today the Authorities regulate who, where, when and how the fisheries can take place. The markets where Zooca operates expect that the company addresses sustainability across the entire value chain. A question is however, if coming regulations for the fishery-based industries will facilitate a development towards more sustainable products?

The paper will discuss how Life Cycle Management (LCM) can promote collaboration between industries and Authorities to develop sector-specific regulations that embrace a holistic product value chain perspective. The goal is that the end-product from the Calanus resources gets a better sustainability footprint in accordance with sustainability standards.

Mutual Recognition Agreement to foster LCA harmonization and efficiently drive sustainable production and consumption frameworks

Benjamin Canaguier[1], Julien Morganti[2], Shifa Meyer[3], Or Galant[4], Pavinee Hasselberg[4], Gustav Sandin[4], Manel Sansa[1]

[1]Schneider Electric, France; [2]PEP Ecopassport; [3]Nexans; [4]EPD International AB

Regulators and customers are more systematically looking at the environmental assessment of products in order to drive their own sustainability strategy (e.g. scope 3 decarbonization) and drive sustainable consumption and production policies (ESPR, Green Claims, EU Green Taxonomy, etc.). Type III Environmental Product Declarations (EPD) are often used as basis to compare similar products and drive decision making. However, this recent increased scrutiny of EPDs has highlighted the lack of comparability due to heterogeneous practices and standards. More specifically, for electrical and Heating, ventilation, and air conditioning (HVAC) equipment, several Product Category or Specific Rules (PCR, c-PCR, PSR) co-existed in different Program Operators (PO) such as PEP Ecopassport, EPD International AB, and others. To foster harmonization of practices and facilitate EPD publication toward better comparability PEP Ecopassport and EPD International AB have signed an ISO 14029 compliant Mutual Recognition Arrangement (MRA) agreement. Both program operators propose to present the challenges and best practices to efficiently set up an MRA in order to mutually adopt product category rules and support industries and regulators with less and more harmonized rules to build up a Life Cycle Assessment for products and hence work toward an improved comparability of such an assessment.

Life Cycle Thinking in Research and Policymaking for Sustainable Consumption

Göran Finnveden[1,2]

[1]KTH Royal Institue of Technology, Sweden; [2]Mistra Sustainable Consumption

Sustainable Consumption is an area with growing policy attention. As noted for example by the IPCC, technological changes will not be enough to reach climate targets, also demand-side measures are necessary. When developing policies for sustainable consumption, a life cycle perspective is instrumental. In this presentation, results from an 8-year Swedish research program (Mistra Sustainable Consumption) involving approximately 30 researchers and 25 partner organisations will be presented illustrating examples of how life cycle thinking is useful and necessary for developing effective sustainable consumption policies. Examples of results include:

• The importance of assessing footprints for the region or country in question for identifying the most important product groups and production countries. These assessment should include a broad range of impacts. We show for example how the Swedish carbon footprint have decreased while the chemical footprint have increased during the same time period (Finnveden et al).

• The importance of rebound effects. Life-cycle studies can identify the potential importance of rebound effects. We have however also shown that some people can almost completely avoid rebound effects when practising consumption with low climate-impacts (Andersson et al). Besides economic rebound effects, also time rebounds can have an impact when assessing lifestyles (Lehner et al).

• The importance of assessing the effectiveness of policies. Life cycle studies can be useful to show impacts of policies which is one important aspect for getting policy acceptance (Ejelöv et al).

• The importance of a consumption-perspective when designing policy instruments. Using a consumption and life-cycle perspective allows a policy-maker in one country to influence emissions also in other countries. This is critical to avoid carbon-leakage and to limit emissions where technological solutions are limited (Morfeldt et al).

Life-cycle studies can however also be used as a defence and for slowing down a transformation requiring a balanced approach.

Session 2.10: Social Sustainability: Data & Method Advancements Part II

Time: Thursday, 11/Sept/2025: 11:30am - 1:00pm
Session Chair: Manuela D'Eusanio, Università degli Studi "G.d'Annunzio" di Chieti-Pescara, Italy
Session Chair: Isabel Susan Wolf, TU Berlin, Germany

Sustainable steel production: Application of S-LCA in German Steelmaking

Gijs Krekel[1,2], Julian Suer[1], Marzia Traverso[2]

[1]thyssenkrupp Steel Europe, Germany; [2]Institute for Sustainability in civil engineering (INaB), Germany

Modern primary steelmaking, that is to say steel produced from iron ores, is typically produced by the blast furnace – basic oxygen furnace route, which in 2022 accounted for 71% of global production. Primary steel production is energy and resource intensive, sourcing vast amounts of raw materials globally, such as iron ores, iron ore agglomerates, metallurgical coal and coke, as well as auxiliary materials such as alloying agents and fluxes. In light of the European Corporate Sustainability Due Diligence Directive (CSDDD), the need to assess the sustainability dimensions of the steelmaking process and its value chain is increasing. Within recent years, the implementation of Life Cycle Assessment (LCA) has become standard practice within the industry. Nonetheless, the LCA methodology addresses only the environmental aspects of product sustainability. The CSDDD requires a more holistic approach, by considering social and socioeconomic impacts as well. As social impacts on stakeholder, e.g. local communities, might not be easily discernable, the need for a systematic framework arises. Social Life Cycle Assessment (S-LCA) according to ISO 14075 allows for the consideration of social and socioeconomic impacts, and has the potential to provide important information on which stakeholders are affected by the steelmaking industry. This study investigates the social impacts of steel production of thyssenkrupp Steel Europe (tkSE), the largest German steel producer, both on site and along its value chain. Through extensive primary data collection at tkSE, and scientifically robust application of the S-LCA methodology according to ISO 14075, valuable insights are generated about tkSEs impacts on its stakeholders. This provides the organization with the scientific basis for the improvement of social conditions on-site. Additionally, it helps the company identify and eliminate any social risks along the supply chain, and move towards true sustainable steelmaking, considering economic, environmental and social factors.

Defining impact subcategories and indicators for battery electric vehicles: a methodological approach for Social Life Cycle Assessment

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The transition to sustainable transportation, exemplified by Battery Electric Vehicles (BEVs), requires comprehensive evaluation across environmental, economic, and social dimensions. Social Life Cycle Assessment (S-LCA) plays a key role in addressing BEVs' social and socio-economic impacts. However, the lack of standardized subcategories and indicators for social impacts remains a significant challenge. This study bridges this gap by developing a methodology to identify, define, and validate social impact subcategories

and indicators specific to BEVs.

A three-step methodology was adopted to prioritize social impact subcategories. First, a materiality assessment was conducted using inputs from EU policies on BEV supply chains, scientific literature, stakeholder consultations, and the Drive Sustainability initiative's Sustainability Assessment Questionnaire. These sources were cross-referenced with UNEP Social LCA guidelines to identify subcategories. Next, social indicators were identified using databases such as PSILCA and the Social Hotspot Database. A Multi-Criteria Decision Analysis framework was applied to score indicators based on achievability, feasibility, interpretability, and relevance.

The study highlights critical impact subcategories, including health and safety, fair salary, forced labor, and Indigenous rights. A total of 19 social indicators were shortlisted and validated through a participatory process involving S-LCA researchers and automotive industry partners. This approach ensured that the selected indicators were scientifically robust, practically applicable, and aligned with stakeholder needs. Key indicators include workplace accident rates, minimum and living wages, and the presence of Indigenous populations.

By prioritizing subcategories and aligning indicators with global and European standards, this study offers a systematic framework for S-LCA of BEVs. The proposed approach enhances transparency, stakeholder engagement, and decision-making, providing a practical tool for evaluating the social sustainability of BEVs.

Job creation in S-LCA: influence of database choice - Case study on jeans stone washing

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Job creation along the life cycle of a product is a policy-relevant indicator, especially in the transition to a circular (bio)economy where different jobs are needed for among else circular economy processes and biomass growth. Job creation potential (JCP) can be obtained using different approaches, and one needs to distinguish between Full-time Equivalent (FTE) Jobs and headcount jobs. Within the context of LCA, the idea is to also consider jobs in background systems for which databases are needed. We focus on yearly FTE jobs derived from worker hours quantities already present in Social LCA databases. JCP can be assessed with databases based on economic Input Output models like PSILCA (Eora) and EXIOBASE. However, these databases generate different results. In this study, the objective is twofold: (1) compute JCP for these different databases, specifying refined ways to calculate and (2) illustrate differences in JCP results along the life cycle for two systems for jeans washing: one using pumice (a natural stone) and the other using F-stone (a multiuse plastic-based material). Jobs were differentiated by gender and skill level, in case of EXIOBASE. Results show a higher number of jobs created for the pumice system, due to the difference in the requirement of chemical products and worker hours involved in waste handling derived from pumice stone. The group with the highest number of jobs was medium-skilled males for both systems and all sectors considered. The number of jobs estimated with PSILCA data are higher than those calculated with EXIOBASE. Differences in results are explained by underlying methodological choices in the databases, like the way worker hours were estimated and the different sectoral classification considered in each database. While this approach is helpful for providing job creation estimations, process-based approaches with worker hours collection not derived from economic databases could provide improved results.

Improving Social Life Cycle Assessment Methodology for Sustainability Reporting: A Case Study on WEEE Management Companies

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Addressing complex sustainability challenges requires companies to adopt innovative strategies that mitigate environmental, social, and economic impacts. CSRD is an essential tool for demonstrating contribution to the SDGs, enhancing transparency, and meeting regulations. A major challenge in CSR is effectively assessing and integrating the social dimension, which is inherently qualitative, influenced by stakeholder dynamics, and shaped by specific contexts.

This study advances Social Life Cycle Assessment (SLCA) methodology for e-waste recycling systems, emphasizing results at the subcategory level rather than individual performance indicators. By aggregating multiple indicators into broader subcategories, this approach offers a nuanced understanding of social impacts and highlights improvement priorities often missed when focusing solely on individual indicators.

The research involved a systematic literature review, expert consultations, and validation of indicators relevant to e-waste management. This process resulted in a framework of 60 social indicators and 32 impact subcategories across five stakeholders, along with definitions and data requirements. A calculation method was developed based on aggregation, normalization, and weighting. This method assigns specific weights to indicators and incorporates their performance values, accurately reflecting their relative importance in total subcategory impact.

An automated Excel tool was created to facilitate SLCA implementation by companies and stakeholders. The method and tool were tested through a case study of an e-waste management company in Ecuador. Results demonstrated that weighting indicators reveals their direct influence on subcategory outcomes. This underscores the need for strategies addressing all indicators within a subcategory to improve social performance. Facilitating the integration of social impacts into corporate sustainability reporting by providing a structured and detailed methodology for measuring and communicating these impacts. By presenting the results at the subcategory level, a more complete and meaningful picture of social impacts is provided, enabling companies to identify and prioritize key areas for improvement.

Advancing Social Life Cycle Assessment (S-LCA) for Public Services: Evaluating Water Supply Systems in the Provinces Venice and Treviso

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This study addresses a significant gap in the existing literature by proposing an innovative methodological framework for social life cycle assessment (S-LCA) applied to public services. The objective is to develop a specific model for assessing the social impact of public services. The case study focuses on the water supply systems of the cities of Venice and Treviso. The aim is to assess the social performance of aqueduct services and identify areas for improvement.

The methodological framework is based on the guidelines of the United Nations Environment Program (UNEP, 2020). Primary data (online surveys and company reports) and secondary data (PSILCA database) were used to analyze the social life cycle inventory. A type I reference scale approach was used for the impact assessment.

The assessment considered 6 stakeholder categories (Workers, Local Community, Users, Children, Society, Government, Public Regulators, and Local Authorities), 43 impacts sub-categories (including 19 newly developed ones), and 115 performance indicators. The results show an overall satisfactory social performance, with some particularly positive areas and others that need to be improved. Of the indicators analyzed, 46

are low risk, 62 are medium risk (compliance with local and international regulations) and two are high risk, particularly concerning perceptions of transparency of services and community satisfaction with communication channels. All stakeholder groups were weighted equally, giving them a uniform relative importance in the overall assessment.

The proposed methodological framework proves its effectiveness in evaluating the social performance of public services at different levels (positive, negative, or potential), despite the challenges related to data confidentiality, the complexity of public services, and the diversity of stakeholders. Although some limitations, such as the representativeness of the sample and the accessibility of the data, were identified, this research represents a significant advance in the application of S-LCA to public services.

Are circular bio-based products also sustainable from a social perspective? The 'Cartiera' case study

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Achieving a sustainable bioeconomy requires a balanced use of sustainable resources that facilitate reuse and recycling (Aguilar et al., 2019; Vogelpohl & Töller, 2021), while also taking socio-economic aspects into account (Falcone et al., 2019). In line with recent EU directives, such as the Corporate Sustainability Reporting Directive (CSRD) and the Corporate Sustainability Due Diligence Directive (CSDDD), this study aims to identify the main risks associated with the leather industry in Italy. By employing the Social Life Cycle Assessment (S-LCA) methodology, the research is focused on the Cartiera fashion laboratory (in Emilia Romagna Region), which produces bio-based products utilizing leather leftovers from fashion companies.

Based on the updated UNEP guidelines (2020), ISO 14075:2024 and on relevant recently published studies (e.g., Rebolledo-Leiva et al. 2023; Vinci et al. 2024), the S-LCA is implemented through three main integrated research steps. The first step includes a social hotspot analysis, using the Social Hotspot Database (SHDB) version 5.0, to identify major risks related to the Italian leather sector and build a preliminary map of the most relevant social impact categories and subcategories. Secondly, interviews with relevant stakeholders are undertaken to validate and integrate the results obtained from the social hotspot analysis. Thirdly, primary data is collected through questionnaires structured into sections representing different stakeholders, i.e., workers, value chain actors, local community, and consumers. For each category of stakeholders, several socio-economic aspects are analyzed (for example, sub-categories such as labor conditions and job creation at the local level) through qualitative, semi-quantitative, and quantitative indicators. The impact assessment stage is conducted by adopting the reference scale approach for evaluating socio-economic performances. The results of this study provide interesting insights, especially for SMEs, which are the main actors involved in the Italian fashion industry.

Advancing Social Life Cycle Assessment (SLCA) for Sustainable Artisanal Gold Mining: Addressing Organized Crime and Ecosystem Impact in Nangaritza, Ecuador

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Artisanal small-scale gold mining (ASGM) serves as a vital livelihood source for numerous communities and has become a significant economic activity in Nangaritza, Ecuador, drawing individuals from across the nation (Mestanza-Ramón, Mora-Silva, et al., 2022). This study explores the potential of enhancing Social Life Cycle Assessment (SLCA) for ASGM in the Amazonian rainforest of Nangaritza by integrating organized crime dynamics and assessing their implications for socio-environmental sustainability. A com-

prehensive literature review has been conducted, identifying methodological gaps and providing the foundation for expanding SLCA to include this dimension (Gold, 2020; Mestanza-Ramón, Ordoñez-Alcivar, et al., 2022).

Additionally, an in-site socio-environmental survey focusing on community impacts and ecological conditions has been applied, offering firsthand data to refine the SLCA framework. The research investigates key hotspots, such as irregular labor practices, child labor, health risks, and community displacement, while evaluating ecological challenges like deforestation, biodiversity loss, and water contamination (Mestanza-Ramón, Cuenca-Cumbicus, et al., 2022). By addressing organized crime and transit ecosystem degradation, the study bridges critical gaps in current SLCA methodologies and enhances their applicability to high-stakes contexts.

The findings aim to guide miners, policymakers, researchers, and investors toward scalable, sustainable solutions that promote economic development, reduce socio-environmental harm, and mitigate criminal activities. This work aligns with global sustainability agendas, offering actionable insights into policy reform, collaborative investment, and capacity-building opportunities (Mestanza-Ramón, Ordoñez-Alcivar, et al., 2022; Mestanza et al., 2021).

By advancing SLCA frameworks to encompass emerging challenges, this research sets a foundation for reasonable and sustainable development in ASGM operations, serving as an essential reference for addressing the complex interplay of social, environmental, and economic factors in artisanal mining.

Proposal of Support Indicators for Social Life Cycle Assessment (S-LCA) for Urban Transport Infrastructure in Brazil

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Sustainability in urban transport infrastructure has traditionally been assessed through life cycle cost analysis and environmental impact evaluations; however, the inclusion of social aspects remains underexplored. The absence of a social life cycle assessment (S-LCA) framework adapted to local realities results in decision-making for transport infrastructure that may perpetuate inequalities and limit benefits for impacted communities. This study uses the Brazilian context to propose support indicators for S-LCA in urban transport infrastructure during the use phase of the life cycle. The methodology involves an adaptation of the ELASTIC (Evaluative and Logical Approach to Sustainable Transport Indicator Compilation) framework. A database comprising 627 sustainable transport indicators was developed from 12 national and international sources. Among these, 219 indicators focus on the social dimension during the use phase of transport infrastructure. These indicators were grouped by theme, resulting in 28 categories. Simple additive weighting (SAW) approach was used to aggregate the weights and derive an overall performance measure for each indicator. The 20 indicators with the highest weights were selected. The final stage involves a sensitivity analysis using 1,000 Monte Carlo simulations, varying the weights assigned to each indicator. The most relevant social indicators identified include accessibility to opportunities and services, the promotion of multimodality, and the extent and quality of infrastructure dedicated to active and public transport. While developed for Brazil, the methodology can be adapted to other contexts. Finally, this study contributes to the advancement of S-LCA and highlights the importance of integrating social perspectives into decision-making processes for urban transport infrastructure.

Systematic Literature Review on Social LCA Applications in Hydrogen Electrolysis for the Energy Sector

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The widespread adoption of hydrogen as a key energy carrier to reduce greenhouse gas emissions entails complex value chains, including international supply routes, with potential effects (positive or negative) on the different sectors society. While sustainable hydrogen deployment is often motivated by environmental and economic goals, the integration of social responsibility and human well-being is equally essential. However, studies exploring the prospective social impacts of hydrogen electrolysis remain scarce, particularly in the energy sector. This study conducts a systematic literature review of the application of Social Life Cycle Assessment (S-LCA) methodology to hydrogen electrolysis, identifying ten relevant case studies. By analysing these studies, the research assesses key social impacts along the hydrogen value chain, identifies trends in S-LCA applications, and maps current practices while highlighting methodological strengths, weaknesses, and hotspots. Quantitative results from case studies, particularly those focused on the same countries, are further examined to identify common patterns. These findings are contextualized through a qualitative analysis of literature and raw data, providing deeper insights into their broader significance. Additionally, this research examines sustainability reports from major electrolyser manufacturers to assess the alignment of corporate social responsibility (CSR) themes with social indicators evaluated in reviewed studies. The analysis reveals a partial alignment: while companies emphasize occupational health, diversity, and ethical practices, gaps remain in addressing broader social issues such as fair wages, local community impacts, and supply chain transparency. The findings underscore the potential of S-LCA as a decision-support tool to enhance the social sustainability of hydrogen technologies. This work contributes to bridging the gap between literature-based and corporate approaches to social sustainability in hydrogen technologies, offering actionable recommendations to advance S-LCA's role within the broader framework of Life Cycle Sustainability Assessment (LCSA) and to support decision-makers in fostering a socially sustainable hydrogen economy.

Session 2.11: Sustainable mobility solutions Part II

Time: Thursday, 11/Sept/2025: 11:30am - 1:00pm
Session Chair: Katharina Gompf, BMW Group, Germany
Session Chair: Tobias Viere, Pforzheim University, Germany

Collaborative Life Cycle Assessment: Integrating Stakeholder Perspectives for Effective Environmental Regulation in the Automotive Industry

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The automotive industry is increasingly subject to new regulatory initiatives based on Life Cycle Assessment (LCA) methodologies. These initiatives are reshaping environmental reporting and are becoming integral to planned legislations by engaging stakeholders in various ways. Scientific communities strive for objectivity in LCA methodologies, ensuring robust and unbiased results. Policymakers leverage these results to develop environmental targets, while companies require practical LCA methodologies to enhance the environmental footprint of their products and services. Collaboration among these stakeholders is crucial for creating effective and applicable LCA methods.

The proliferation of LCA-based reporting initiatives has led to a fragmented landscape, with numerous, often non-harmonized requirements. This fragmentation makes it time-consuming and challenging for companies to comply with these diverse regulations. OEMs face the additional challenge of managing their portfolios while adhering to regulations with conflicting methodological requirements that incentivize different outcomes. Legislators need to provide a robust database, and input from science is essential to develop reliable yet applicable calculation models. Harmonizing these initiatives and improving the granularity of data and models are essential steps towards more effective environmental management for OEMs.

Integrating diverse stakeholder perspectives in LCA method-building is vital for developing practical, effective, and comprehensive regulatory frameworks. This collaborative approach will enable the automotive industry to meet regulatory requirements while genuinely improving its environmental performance.

LCA methodology for zero-emission vehicle (ZEV): Selection of impact categories and normalisation factors by consensus building

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Transport is responsible for 30% of the EU's greenhouse gas emissions, underlining the urgency to develop and foster sustainable mobility services in Europe like zero tailpipe emissions vehicles (ZEVs). Therefore, robust Life Cycle Sustainability Assessment (LCSA) methodologies are needed to inform decision makers, and evaluate and monitor the sustainability of ZEVs. TranSensusLCA (TSLCA) aims at developing a European commonly accepted LCSA approach for ZEVs. The project aspires to improve representativeness and comparability between LCAs. Gathering relevant stakeholders from industry and research, a realistic and scientifically sound LCA approach is being conceived and harmonized. By consensus, TSLCA will help deci-

sion makers to provide sustainable products and optimize mobility solutions.

One of the key aspect of LCSA is Life Cycle Impact Assessment (LCIA) and normalisation. However, use of different impact categories (IC), indicators and normalisation factors (NFs) hinders the comparison of diverse LCA studies. To address this challenge, TSLCA proposes to standardise key elements of LCIA and ensure comparability, including IC, indicators, assessment methods, and normalisation.

Following a TSLCA consensus building process, a comprehensive selection of environmental impact categories was made, encompassing relevant issues within the product's supply chain. To evaluate the relevance of each type of impact for ZEVs, a list of existing LCA IC were analysed and scored based on five criteria: 1) robustness, 2) relation to planetary boundaries (PBs), 3) importance for ZEVs, 4) data availability, and 5) ease of use. Seven IC or indicators have been selected as mandatory after three voting rounds.

Though normalisation is seldom mentioned in guidelines and considered a subjective step, TSLCA acknowledges its usefulness and recommends it as optional. After a review and evaluation of existing NFs, the NFs in relation to PBs were recommended. Although not completely mature yet, it was deemed that an absolute approach is the most relevant in TSLCA.

A Sectoral Tool for Carbon Footprint Assessment of Passenger Vehicles: Enhancing Transparency and Data Accessibility

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Decarbonization of the transport sector requires not only innovative technologies but also accessible tools to guide decision-making across the supply chain. As part of the "From Cradle to Gate" project, led by Center for Sustainability Studies of Fundação Getulio Vargas (FGVces) in partnership with State University of Campinas (UNICAMP), a sectoral carbon footprint assessment tool was developed to support the Brazilian automotive industry in quantifying and managing greenhouse gas (GHG) emissions associated with vehicle production.

Designed as a user-friendly platform, the tool enables automakers and suppliers to calculate the life cycle carbon footprint of light duty vehicles from material extraction to factory gate. The project and tool address a significant gap in the Brazilian automotive market, which lacks studies based on primary data within this scope and a sector-specific tool for such calculations

It integrates emission factors from regionalized life cycle inventory (LCI) data, prioritizing key materials such as steel, aluminum, and polymers. By accounting for Brazil's predominantly renewable energy mix and primary data collected from local suppliers and automakers, the tool provides more accurate and representative results than global datasets.

The sectoral tool not only promotes transparency but also fosters collaboration across the mobility value chain by standardizing methodologies and facilitating data sharing, addressing a critical challenge in LCA adoption. This tool provides the Brazilian automotive industry with a benchmark for sustainable practices, fostering innovation while supporting compliance with regulatory frameworks,. as Brazil's emerging Green Mobility and Innovation Program (Mover Program – Law Nº 14.902/2024). Additionally, it empowers stakeholders to identify emission hotspots, evaluate alternative production strategies, and implement circular economy practices.

The tool development process, main results and comparisons between different vehicle configurations will be presented at the conference, allowing companies to reproduce this model in a scalable way for other regions.

TranSensusLCA: Framework for automobile LCA of the future

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Passenger cars and light commercial vehicles contribute approximately 19% of the European Union's (EU) carbon dioxide (CO2) emissions, underscoring their importance in achieving the EU's climate neutrality goals by 2050. Recent regulations, including a 100% CO2 reduction target for new vehicles by 2035, demand transformative changes in the automotive sector. These include adopting new powertrain systems, mobility infrastructure, and innovative concepts for connected, automated vehicles, as well as the realization of smart, climate-neutral cities. Supporting this transformation requires robust, reliable, and harmonized life cycle assessment (LCA) methodologies for zero emission vehicles to comprehensively evaluate the environmental, social, and economic impacts of emerging technologies and mobility solutions. Despite the recognized importance of LCA, the transport sector is still struggling to adopt LCA approaches due to inconsistencies in methods, tools, and difficulties in accessing and managing real-world data.

The EU-funded TranSensus LCA project addresses these challenges by developing a European-wide, real-data-based LCA approach tailored to zero-emission road transport. It actively engages stakeholders from the automotive and battery value chains, including OEMs, suppliers, and research institutes and herewith underlines the applicability of the developed approaches. The project aims to enabling industrial clients to improve decision-making and operational consistency across the electromobility value chain, such as evaluating the sustainability of powertrains or battery technologies with greater accuracy. A major achievement of TranSensus LCA is a comprehensive ontology framework for a European-wide Life Cycle Inventory (LCI) database. Using Python-based automated procedures, the project minimizes errors and ensures scalable data integration. Accessible through tools like Protégé, the ontology allows industrial users to explore and analyze data relationships efficiently, streamlining decision-making processes. By providing a harmonized, auditable LCA methodology, TranSensus LCA empowers mobility providers and planners to optimize sustainable operations, contributing to climate change mitigation while enhancing the competitiveness of Europe's electromobility sector.

An LCI-based decomposition analysis to assess consumer behavior mitigations and propose demand-side strategies for the car mobility sector: the case of Switzerland.

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A successful ecological transition requires coupling supply-side mitigations (improvement of the production processes, technologies, and infrastructure) and demand-side mitigations (changes in consumer behaviors and societal practices). However, environmental assessment model like Life Cycle Assessment (LCA) are typically supply-centered, built to compare technologies. Consequently, demand-side mitigations are underrepresented in transition pathways and case studies, undermining the success of ecological strategies.

Therefore, this work aims to develop an original demand-centered method to capture and compare behavior changes in automobile mobility compatible with supply-centered methods. Literature categorizes demand-side mitigations into three categories: Avoiding (e.g. reducing distance traveled), Shifting (e.g. electrification, downsizing) and Improving (e.g. eco-driving).

Using a bottom-up approach, this study builds decomposition analyses from parametrized Life Cycle Inventories (p-LCI). A p-LCI structures the inventory using raw parameters and equations to quantify flow intensity. First, LCAs were conducted from p-LCIs to determine the unit impacts per km of gasoline and electric vehicles. The results were multiplied by technology penetration rates and total distance traveled to calculate

the parametrized absolute impacts of Swiss car mobility.

Second, LCA results were aggregated and derived into a decomposition analysis that links total impact reductions to supply- and demand-side mitigations. Sectoral reduction targets were derived from planetary boundaries and political commitments. Supply-side mitigations were modeled using prospective inventories of technological innovations and background process improvements, estimating the achievable reductions from supply-side.

The remaining reductions were attributed to demand-side parameters, aggregated into four key levers: electrification, downsizing, eco-driving, and distance reduction. The decomposition model generated demand-side strategies, distributing the remaining required reductions among these efforts to ensure alignment with sectoral targets. For instance, to achieve Swiss car mobility targets in 2050, maintaining distance traveled constant would require electrification (> 60%), downsizing (30-50% of car/engine size reductions) and eco-driving (15-30% of speed/aggressiveness reductions).

From Cradle to Gate: Addressing Data Gaps in the Carbon Footprint of Passenger Vehicles in Brazil

Juliana Picoli[1], Layla Lambiasi[1], Letícia Gavioli[1], Lucas Cesilla[1], Tiago Zillio[1], Guarany Osório[1], Paulo Lima[2], Rafael Mosquim[2], Joaquim Seabra[2], Mario Monzoni[1]

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The transportation sector is a major contributor to global greenhouse gas (GHG) emissions, with passenger vehicles playing a key role. In Brazil, road transport accounts for 11% of national GHG emissions. In response to increasing regulatory and market demands for transparency in environmental performance, the "From Cradle to Gate" project, led by Center for Sustainability Studies of Fundação Getulio Vargas in partnership with State University of Campinas, aims to calculate the life cycle carbon footprint of passenger vehicles manufactured in Brazil. This project focuses on providing robust, representative life cycle inventory (LCI) data, enabling more accurate and transparent assessments of the sector's environmental impact.

A key challenge is the availability and quality of primary data from the automotive supply chain, especially for materials such as steel, aluminum, and polymers. To address this gap, the project actively engages with automakers and suppliers to gather local data and adapt global datasets to better reflect the Brazilian reality. The methodology employs Life Cycle Assessment (LCA) principles and integrates regionalized emission factors from stakeholder data collection for materials and processes that account for approximately 80% of the vehicle's carbon footprint.

Preliminary results reveal the significance of regionalized LCI data in identifying emission hotspots and informing strategies for emissions reduction. The project also explores how to balance transparency with data confidentiality in industry-wide collaborations. By providing emission factors for key materials and processes, the project contributes to the establishment of a standardized framework for carbon footprint assessment in Brazil's automotive sector, aligning with emerging regulatory requirements such as Brazilian Green Mobility and Innovation Program (Law Nº 14.902/2024).

This study will provide insights, preliminary findings, challenges and achievements outcomes from the ongoing project "From Cradle to Gate", highlighting its contribution to filling critical LCI data gaps and fostering a transparent and competitive environment for sustainable production.

On the role of assumptions and methodological choices in LCA-based decision-making – the case of shared e-scooters in Finland

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Climate impacts of free-floating shared electric scooters (shared e-scooters) have been studied for several cities in Europe, and globally, but not in Finland. According to existing research, climate impacts of riding a shared e-scooters quantified per 1 passenger-kilometre (pkm) can be both lower than alternative means of personal transport in cities, but it can also be significantly higher in some cases. Nevertheless, the impacts of an individual shared e-scooter ride remain relatively low. However, from the perspective of the whole transport sector and its decarbonisation, it is important to understand the system level impacts. How significant are they compared to the absolute impacts caused by urban transport? How can they be optimized? As more than 50 thousand shared e-scooters cruise the streets of Finland, understanding the system level impacts is more than relevant to facilitate the public debate.

We build on publicly available data, interviews, and on inventory data found in existing literature and perform an explorative life cycle assessment (LCA) of a shared e-scooter system in Helsinki, Finland. Due to the limited availability of primary data, we explore the role of assumptions and methodological choices on the results. We present a glimpse of preliminary results based on scenario analyses, both per pkm and as a system. Our results contribute to the heated public debate concerning shared e-scooters, which currently revolves mainly around the issues of safety, health, regulation, and the used of urban space. Bringing the attention also to the environmental impacts contributes to a more holistic debate and to a better decision making.

Balancing Comparability, Applicability and Accuracy: Insights from Applying a Consensus-Based LCA Methodology in the Automotive Industry

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The growing number of initiatives to develop life cycle assessment (LCA) methodologies tailored to the automotive industry highlights the need for common guidance. Traditionally, vehicle manufacturers have published LCAs based on proprietary methods aligned with ISO standards. However, these reports often lack transparency regarding methodological choices, complicating result interpretation and comparability.

This study contributes to the development of a comprehensive consensus-based LCA methodology by testing a draft version of it on zero-emission vehicles (ZEV). To evaluate robustness, two parallel LCAs—one for passenger cars and one for trucks—are conducted by independent practitioners, assessing consistency, interpretative variation, and practical implementation. This case study is part of a larger initiative to create a consensus-based and harmonized LCA methodology applicable across zero-emission road transport.

The consensus-building process involves iterative voting rounds, where methodological building blocks are selected based on a two-thirds majority. The voting rounds focus on methodological aspects such as system boundaries, functional unit, End-of-Life modelling and data quality requirements. While this approach ensures collective agreement on individual elements, it risks producing a methodology that lacks overall coherence. To mitigate this, the methodology undergoes a testing phase to evaluate its feasibility and coherence, identifying ambiguities, overly complex procedures, and inconsistent definitions.

The findings from this case study will inform the broader development of a full LCA methodology, ensuring it is both coherent and practically applicable. Additionally, it will highlight areas where interpretation remains variable, offering a real-world perspective on the consequences of differing assumptions. Ultimately, this case study contributes to the ongoing development of a harmonised European industry-wide LCA framework, fostering comparability and informed decision-making for zero-emission vehicles.

Methodological approach towards circular solutions applied on a powertrain for electric trucks

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The use of specific tools in product development is a common approach for the implementation of design strategies and a wide range of design guidelines have been published. Nevertheless, the selection of the relevant CE-strategy and its implementation is still a challenging task. To address this issue a fifth-step approach towards circular solutions has been developed following the double diamond innovation framework.

The intended paper describes the results of the evaluation and application of this approach on a electrical powertrain for heavy vehicles and the developed circular solutions for the components: inverter, motor and gear box which is currently ongoing with industry.

In the first step of the methodology the relevant CE loop/strategy is selected for a specific product based on a guided questionnaire. For a simplified approach, the 10 Rs of have been summarized in three different loops: short (e.g., Recycling), medium (e.g., Remanufacturing), long (e.g., Repair). The selection of the strategy is of most importance as it directs the whole development process. Next to circularity specific aspects also the environmental profile or critical raw materials influence the selection.

Secondly the specific CE-design criteria (based on the relevant CE strategy) must be evaluated if fulfilled, nor fulfilled or not relevant. In each CE strategy 20-30 relevant design criteria are listed for evaluation. Thirdly the design criteria declared as relevant and not yet fulfilled are considered for an innovation workshop to develop improvement ideas for the selected design criteria. Fourthly the ideas are evaluated according to effort for realization, whereas the effort can be personnel, cost but also resources and their environmental impact. Lastly the various selected ideas for each design criteria are listed in a morphological box and ideas which fit together are combined as possible product concepts.

Next circular business models are developed and integrated into the methodology.

Session 2.12: LCSA advancements and implementation in building Part I

Time: Thursday, 11/Sept/2025: 11:30am - 1:00pm
Session Chair: Matthias Fischer, Fraunhofer Institute for Building Physics IBP, Germany
Session Chair: Jana Gerta Backes, Meo Carbon Solutions GmbH, Germany

From Voluntary Initiatives to Regulation Through Collaboration: Embodied Carbon Progress in Australia and New Zealand

Barbara Nebel

thinkstep-anz, New Zealand

Collaboration between industry, government, green building councils, as well as cross-Tasman cooperation of the LCA communities, has driven progress in addressing embodied carbon in Australia and New Zealand 2014. Awareness has evolved into structured action through regulations, industry standards, and voluntary initiatives.

The journey began in 2014 when the Australian Life Cycle Assessment Society (ALCAS) and the Life Cycle Association of New Zealand (LCANZ) launched the Environmental Product Declaration (EPD) programme, providing a framework for standardised embodied carbon assessments. In 2018, The Carbon Footprint of New Zealand's Built Environment report highlighted that buildings and infrastructure contribute up to 20% of national emissions, with embodied carbon accounting for approximately half. This report significantly shifted the perception of the built environment's contribution to carbon emissions from 2% to 20% in New Zealand.

In 2020, the New Zealand Ministry of Business, Innovation & Employment (MBIE) launched the Building for Climate Change programme, aiming to implement mandatory whole-of-life carbon assessments for buildings. A year later, in 2021, the Green Building Council of Australia (GBCA) and thinkstep-anz published Embodied Carbon & Embodied Energy in Australia's Buildings, warning that without intervention, embodied emissions could constitute up to 85% of a building's total footprint by 2050.

Momentum continued in 2023 when NABERS initiated a consultation on an Embodied Carbon Rating Tool to establish a standardised measurement framework. In 2024, updates to the Australian National Construction Code incorporated considerations for embodied carbon, further embedding carbon assessment into regulatory frameworks. .

Challenges include data gaps, inconsistencies in measurement frameworks, and the need for international harmonisation. However, collaboration and policy advancements are positioning both countries to meet carbon neutrality goals. This presentation will explore the progress, challenges, and future opportunities in reducing embodied carbon in the built environment.

A new ecoinvent framework for the construction sector – towards a transparent and granular concrete supply chain

Enrico Bonanno, Avraam Symeonidis, Emilia Moreno Ruiz

ecoinvent, Switzerland

The construction sector is a major contributor to greenhouse gas emissions and raw material consumption, with approximately 7% of global anthropogenic emissions related to the cement industry alone (Miller et al., 2018; UNEP, 2024). Concrete, the second most consumed material by mass after water, drives this impact through large-scale cement production (Monteiro et al., 2017). Rising global cement demand, demographic shifts, and climate mitigation policies make accurate assessment of the concrete supply chain's environmental impact essential for informed decisions, highlighting the need for reliable and transparent data (Griffiths et al., 2023).

Despite available recognized methodologies and substantial advancement in the academic field, significant gaps remain in methodological consistency across studies and available data framework. Current work often focus on emissions from clinker production and energy use while neglecting or generalizing other aspects of the supply chain. These include raw material extraction, transportation, pre-processing, and the role of machinery and infrastructure in cement and concrete production. Furthermore, published data often lack transparency and rely on different system boundaries and modeling approaches, making it difficult to establish a unified framework for evaluating the sector's impacts. These limitations hamper the creation of a cohesive numerical framework that can produce quantifiable and comparable environmental data and foster comprehensive environmental strategies.

To address these challenges, ecoinvent has developed an innovative methodology that prioritizes transparency and granularity in impact assessments. This framework covers the entire concrete supply chain—from raw material extraction to concrete mixing—integrating diverse machinery, energy sources, and industrial processes. By utilizing highly parameterized models that interact dynamically, this approach enables reproducible, verifiable, and customizable environmental assessments of the concrete supply chain. With this framework, ecoinvent establishes a foundation for a novel evaluation of the construction sector's impacts, enabling our users to quantify and understand environmental impacts related to concrete manufacturing.

Applying time value of carbon to structural design LCA decision-making

Harry Watt[1,3], Buick Davison[1], Peter Hodgson[2], Chris Kitching[3], Danielle Densley Tingley[1]

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Should we value today's emissions higher than those in the future? If we do, how does that change our approach to decarbonise construction? This research investigates these questions and the incorporation of Time Value of Carbon (TVoC) into Life Cycle Assessment (LCA) for building structures. Traditional LCA often overlooks the temporal dimension of climate change, treating all emissions as equally impactful regardless of their timing. However, the long lifespans of buildings necessitate considering the long-term consequences of construction decisions.

This study explores how TVoC, a concept borrowed from economics and climate science, can enhance LCA by assigning a discount rate to delayed emissions. This approach acknowledges uncertainties surrounding future emissions scenarios, the potential for technological advancements in decarbonisation, and the urgency of mitigating immediate climate impacts. Various arguments and methods for incorporating TVoC into structural design LCA have been investigated, including:

Buying time: Incorporating potential benefits of delaying emissions to allow for technological and societal

transitions to decarbonise electricity generation and material production.

Spreading the burden: Assessing the cumulative impact of emissions over time through the inclusion of climate science Impulse Response Functions to model the decay of greenhouse gasses through ongoing atmospheric processes.

Modelling uncertainty: Factoring in the social time preference argument from actuarial science to weight certain, near-term emissions higher than uncertain, long-term emissions.

By incorporating TVoC into LCA, decision-makers can gain a more nuanced understanding of the long-term environmental consequences of their choices. This can lead to more informed decisions regarding structural design strategies (e.g. retrofitting vs. demolition, adaptability vs. optimisation) and allows for the balance of short-term and long-term sustainability goals in the built environment. As such, this research contributes to advancing LCA in the building sector by incorporating the temporal dimension of climate change and providing a more robust framework for evaluating long-term sustainability.

Comparative Life Cycle Assessment of Pyrolysis Based Sustainable Phenolic Compound Production

Dineshkumar Muniyappan, Damien Arbault, Lorie Hamelin, Rebecca Belfiore

Toulouse Biotechnology Institue, Bio & Chemical Engineering, Toulouse, France

The significant utilisation of renewable biomass remains difficult primarily because of their complex biochemical constituents and low selectivity for its end products. Herein, we recommend a biomass pyrolysis followed by a solvent extraction process to efficiently recover phenol while also generating valuable co-products that can substitute fossil-based resources and reduce overall fossil energy demand. A detailed consequential life cycle assessment (LCA) was performed to quantify the energy use and environmental impacts of the pyrolysis biorefinery as compared to traditional approaches. Additionally, the use of pyrolysed biochar as a soil amendment application contributes to carbon negativity, while the combustion of bio-oil and non-condensable gases and wood dust generates heat and electricity, partially substituting conventional energy sources. The result highlights biomass supply chains such as indirect land use change, type of pyrolysis technology, yield of co-product and its application, also choice of marginal suppliers and these factors have a direct impact on the environmental performance of pyrolysis based biorefineries. Also, the sensitivity analysis one at the time (OAT) of the major parameters identifies possibilities for process optimisation, such as reducing the energy consumption and increasing phenol production. Results obtained in this study are intended to deliver the evidence for industrial stakeholders and policymakers to make the right decisions and support investments toward a low fossil carbon future.

Koti Banal Architecture of the Himalayan State of Uttarakhand (India): A Case of Circularity and Sustainability

Richa Kumari, Syed Ifrah Asfar, Smriti Saraswat

Indian Institute of Technology Roorkee, India

Indigenous building practices offer invaluable solutions for sustainable change, particularly in the context of the built environment. The Himalayan state of Uttarakhand (India) holds immense wisdom in this regard, coexisting with its fragile ecosystem. The Koti Banal style of architecture, over a thousand years old, demonstrates extraordinary resilience to climate change and potential for disaster mitigation while embodying community-based knowledge and sustainability (material, cultural, social, and environmental). Built with stone and timber, these structures exemplify longevity, local adaptability, and circularity.

Lifecycle Assessment (LCA) evaluates the environmental impact of a material or process throughout its

lifecycle, while Social Lifecycle Assessment (S-LCA) addresses social and socio-economic concerns. Together, these methods can validate the sustainability of Koti Banal architecture, decipher its effects, and offer scalable models for resource efficiency and preservation.

The Koti Banal Architecture has transcended through generations, integrating cultural narratives and ecological knowledge, thus representing a living connection between people and their environment.

Koti Banal architecture integrates cultural narratives and ecological wisdom, representing a living connection between people and their environment. This paper undertakes an in-depth lifecycle study of building materials in the context of Koti Banal architecture. Using LCA and S-LCA methodologies, aided by tools like OpenLCA and SimaPro, it quantifies the sustainability impacts of these practices. Case studies of typical Koti Banal typologies analyze resource and material flows, providing pathways for designers and innovators to adapt and scale these traditional practices.

By grounding the discussion in this richly contextualized setting, the paper aligns with Sustainable Development Goals: SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 17 (Partnerships for the Goals). It showcases the fusion of traditional knowledge with contemporary sustainability needs, promoting ecosystem stewardship and cultural heritage preservation.

LP2: Lunch & Poster

Time: Thursday, 11/Sept/2025: 1:00pm - 2:30pm

Life Cycle Assessment of Carbon Capture via Dynamic Carbonation of Mineral Waste: Insights from the Mineral LOOP Project

Delphine Lina Cerica[1], Elise Aubry[2], Archibald Carlier[3], Ikbal Saqout[4], Séverine Marquis[5], Damien Bruyere[6], Sophie Grigoletto[1], Luc Courard[1], Laureen Brocard[7], Angélique Léonard[1]

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The Mineral LOOP project explores an innovative approach to carbon capture through dynamic carbonation of mineral waste, with a focus on industrial waste streams. Utilizing an industrial pilot plant, the project investigates various waste types—including demolition wastes and thermal process residues—for their CO2 sequestration potential and compatibility with dynamic carbonation. The goal is to convert these materials into durable, secondary construction products, such as fillers, that contribute to a circular economy while offering a viable pathway for large-scale carbon sequestration.

A Life Cycle Assessment (LCA) of this CO2 capture strategy is integrated into the Mineral LOOP project, serving as a critical decision-support tool. The LCA has two main objectives: (1) to support eco-design through each stage of waste processing, carbonation, and recycling operations, and (2) to evaluate the environmental relevance of this new recycling route by comparing its impacts to those of conventional waste treatments. This study mainly relies on primary data from the project's industrial partners, including both conventional waste treatment data and upscaled measurements from the Mineral LOOP pilot plant. It employs an attributional approach for modeling and applies the substitution method to address the multifunctionality associated with recycling.

In line with climate targets and industry's commitment to sustainable practices, the Mineral LOOP project highlights the essential role of cross-industry partnerships in advancing carbon capture solutions. By driving innovation in the valorization of mineral waste, this initiative paves the way for novel carbon capture strategies across sectors, while promoting circularity and reinforcing the foundation for a more sustainable and resource-efficient construction industry.

LCA-based certification system development for clean hydrogen and CCU technologies/products in South Korea

Jina Choi[1], Jungae Lim[1], Jinjoo An[2]

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South Korea is advancing its hydrogen economy and Carbon Capture and Utilization (CCU) industries as key strategies to achieve carbon neutrality by 2050. To ensure environmental reliability in these sectors, the Korean government is developing a certification system based on Life Cycle Assessment (LCA). This study analyzes the frameworks for Korea's clean hydrogen certification and CCU technology and product certification, focusing on the evaluation of greenhouse gas (GHG) emissions and reduction impacts throughout their lifecycle. The clean hydrogen certification system, implemented in 2024, certifies hydrogen with GHG emissions of less than 4 kgCO2e per kg-H2 during production and import processes. This system is closely linked to the Clean Hydrogen Portfolio Standards (CHPS). Clean hydrogen is categorized into four grades based on emission levels, with a "well-to-gate" approach applied for emissions calculation. Meanwhile, South Korea is currently developing a certification system for Carbon Capture and Utilization

(CCU) products, with a strong emphasis on evaluating greenhouse gas (GHG) reduction based on LCA. This study compares domestic and international LCA guidelines applicable to CCU technologies to identify critical gaps and challenges within the evolving Korean certification framework. By analyzing methodological approaches and implementation standards, the study suggests pathways to enhance transparency and facilitate market acceptance. The results are expected to inform policymakers and industry stakeholders, providing strategic guidance to promote the sustainable adoption of CCU technologies in alignment with national carbon neutrality goals.

Integrating Prospective LCA and TEA: Challenges, Proposed Solutions, and Pathways for Sustainable Design and Decision-Making

Ekinsu Akdogan[1], **Karel Van Acker**[1,2,3]

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There are currently numerous efforts to decarbonize manufacturing processes, including the development of advanced carbon capture technologies and innovative processes driven by hydrogen-based energy sources. However, even if a process does not cause direct environmental harm, it may still result in indirect CO2 emissions. Moreover, any emerging technology designed to replace a carbon-intensive one must also be economically feasible. This is why integrating life-cycle analysis (LCA) and techno-economic assessment (TEA) into a single methodology is essential: it enables the systematic identification of trade-offs between economic, environmental, and technical performance at an early design stage, and provides more accurate decision support. Therefore, integrated assessment offer a stronger foundation for sustainable policy-making, investment strategies, and innovation roadmaps, compared to the cases in which they are assessed separately. However, integrating prospective LCA and TEA has several challenges. This study addresses these challenges by identifying gaps in the current literature, proposed potential solutions, and evaluating the limitations of these solutions through a systematic literature review. The findings present an up-to-date perspective on the current state of integrated prospective assessments, guiding future research toward the development of more comprehensive methodologies. While most integrated assessments provide sector-specific insights, the outcomes of this research can support the creation of a framework that can be applied across multiple sectors.

Combined assessment of GHG emissions and associated costs of hydrogen use in Japan

Ren Akami, **Norihiro Itsubo**

Waseda university, Japan

Japan formulates its Basic Energy Plan based on the S+3E concept (Safety, Energy security, Economic efficiency, and Environment) to define the fundamental direction of its energy policy. In 2021, the 6th Basic Energy Plan was developed, summarizing current energy challenges and strategies for overcoming them with a view toward achieving carbon neutrality by 2050 and addressing climate change. The 6th Basic Energy Plan emphasizes the use of hydrogen and ammonia power generation to decarbonize thermal power plants, recognizing hydrogen as an essential secondary energy source for achieving carbon neutrality.

Given this background, it is necessary to conduct a quantitative evaluation of environmental impacts (corresponding to “Environment” in S+3E) and economic burdens (corresponding to “Economic efficiency”) prior to the commercial application of hydrogen technologies. Moreover, since economic burdens are closely related to stable energy supply, these evaluations can also contribute to assessing “Energy security.”

This study aims to quantitatively evaluate environmental impacts using GHG emissions assessment based

on the Life Cycle Assessment (LCA) approach and economic burdens through cost analysis. The scope of the evaluation includes hydrogen transported to Japan and the electricity generated using that hydrogen. The study considers various hydrogen production methods, such as coal gasification, natural gas reforming, and water electrolysis. Additionally, it examines transportation methods to Japan, including liquefied hydrogen transport, ammonia transport, and liquid organic hydrogen carrier (LOHC) transport.

Through this evaluation, the study seeks to quantify the environmental and economic burdens associated with achieving Japan's target hydrogen adoption levels in a future hydrogen society and to visualize the decarbonization effects of hydrogen energy use from a comprehensive perspective.

How a Prospective Life Cycle Assessment Affects a Medium Voltage Switchgear

Luca Marcolongo, Simone Carnì, Greta Bacchelli, Marco Tomasoni, Gabriele Campadello, Seila Rodriguez Vilches

ABB ELDS Technology center

The willingness to communicate environmental performance is driving the adoption of standard and robust means for analyzing environmental impact indicators in the different phases of the product life cycle.

A common methodology for calculating the environmental impacts of products is Life Cycle Assessment (LCA). This methodology covers the entire life cycle of a product, starting from the raw materials used in the components manufacturing to the transport, the use stage, and up to the disassembly and disposal of the material at the end of the product life.

The standard rules however don't fully capture all the sustainability aspects. This paper investigates an innovative approach to evaluate and communicate the environmental performance of the electricity distribution network components.

In this study, the product's environmental impacts are studied applying two different methodologies, the standard LCA and the more innovative prospective LCA. The aim is to evaluate the pros and cons of applying each methodology and determine which one is recommended based on the study's scope.

A key element of prospective LCA is Shared Socioeconomic Pathways (SSPs) scenarios used as background data. By shedding light on the intricate interplay between technological innovation, environmental considerations, and global energy scenarios, the SSPs scenario guides the possible future developments of the product's environmental impacts. The future projections of this research aspire to guide the development of Medium Voltage systems that are reliable and aligned with the imperatives of a low-carbon future.

The outcome of this study, with its new input parameters and functional approach

compared to the standard scheme, offers a unique perspective that provides a more comprehensive assessment of the sustainable development of new products.

Optimizing the penetration pathways of upgraded product to minimize carbon emissions

Wenjing T. Gong, Ichiro Daigo

The University of Tokyo, Japan

Human activities, primarily through carbon dioxide emissions, have driven global surface temperatures to rise by 1.1°C above one hundred years ago. The promotion of technology upgrading, such as the efficiency improvement for electronics, is thought to be a measure in reducing carbon emissions. However, the accelerate promotion of upgraded product also coincides with the early retirement of conventional ones, causing additional environmental burdens. While previous studies primarily focused on the environmental

impacts of single-product upgrades, a research gap remains regarding the environmental impacts during the dynamic process of the upgraded product penetration in replacing conventional ones for the whole society. More attention should be directed towards modeling relatively best way for carbon reductions during the upgraded product penetration. Material flow analysis (MFA) is a methodology used to analyze material flows and stocks within defined systems, but the traditional MFA model limits the penetration of upgraded product to the inflows, which are decided by the stock change and lifetime distribution. It cannot model the accelerate promotion of upgraded product by shortening the lifetime problem of conventional ones. Therefore, this study constructed a multi-stock-driven model that includes both the upgraded and the conventional product stocks to optimize the penetration pathways of upgraded product to minimize carbon emissions. Modular life cycle assessment method is incorporated to model the environmental impact. The results indicate that the proportion of carbon emissions at different life cycle stages will affect the optimization of the penetration rate. Rapid penetration of the upgraded product will result in inversely proportional decrease in the service life of the conventional product. With the acceleration of the penetration rate of upgraded product, the change of penetration rate is more sensitive to the carbon emissions during the waste management stage for conventional product.

Development of 2020 Waste Input-Output Table in Japan as a tool for measuring and assessing circularity performance

Atsushi Fukada[1], Yasushi Kondo[1], Yuki Ichisugi[2], Norihiro Itsubo[1]

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Waste management, as emphasized in SDG Goal 12, plays a crucial role in our daily lives, spanning from industrial activities to final consumption. Additionally, the publication of ISO 59020 in May 2024 has established a global standard for evaluating circularity performance, highlighting the growing importance of quantitatively assessing circularity to build a sustainable society.

In response to these developments, our research focuses on developing the 2020 Waste Input-Output (WIO) Table as a tool for analyzing the circularity of waste generated by industrial activities, while reflecting the recent industrial structures in Japan. The WIO Table expands on the conventional monetary Input-Output Table by integrating physical waste data and extending the representation of waste treatment sectors. This comprehensive framework allows for the evaluation of waste flows, including how production-induced waste is treated, the extent of recycling within industries, and the amount of waste ultimately disposed of without being circulated. Analytical case studies using WIO models have already demonstrated their effectiveness in Asia and Europe.

To construct the updated WIO Table, our research integrates the 2020 Input-Output Table for Japan, published in June 2024, with statistical waste data from Japan's Ministry of the Environment and waste treatment performance data obtained from local governments.

The updated WIO Table provides a platform to explore the development of waste circularity indicators, using one of the core strengths of input-output analysis: the ability to account for indirect impacts across industries. Ultimately, our research aims to establish evaluation methods derived from the WIO Table as globally recognized tools for assessing circularity performance in industrial sectors, contributing to the realization of a more sustainable society.

Challenges and Opportunities in S-LCA for Compliance-Driven Innovation

Julieta Díez-Hernández, Sonia Martel-Martín, Jesús Ibañez, Ana García-Moral, Israel Carreira-Barral, David Blanco-Alcántara, Óscar López-De-Foronda

Universidad de Burgos, Spain

The imperative to integrate social impact metrics into early-stage innovation assessments reflects a broader shift toward holistic and compliance-ready value creation. Yet, Social Life Cycle Assessment (S-LCA) frameworks remain underdeveloped for technologies at low Technology Readiness Levels, where product functions, stakeholders, and value chains are still emerging. This study critically examines both conceptual and operational limitations of S-LCA in guiding socially responsible innovation in these uncertain contexts.

Through a case study on a smart textile prototype within the EU-funded Convert2Green project, this contribution explores how participatory, justice-oriented methods can overcome the rigidity of conventional database-driven approaches. Actor-Network Theory and Multiple Constituency Theory are used to map human and non-human actants, while a Rawlsian ethical lens informs the prioritisation of vulnerable stakeholders. A mixed-method design, combining stakeholder mapping, subcategory co-definition, and a TAM-based survey, was implemented to identify social priorities relevant to design-stage decision-making.

By adapting S-LCA to address the challenges derived from little information and high uncertainty common in low-TRL environments, this contribution imagines pathways for businesses to align their reporting practices with the SSBD and CSRD's requirements for transparency and accountability.

Findings show that users and supply chain workers consistently prioritise labour conditions, data privacy, and safety for vulnerable groups. These insights align closely with the CSRD's emphasis on stakeholder relevance and materiality. By adapting S-LCA to support early compliance with evolving regulatory frameworks, this work proposes a developmental role for social assessment, one that enhances transparency, stakeholder legitimacy, and ethical accountability in innovation ecosystems.

Assessing Social Aspects within the Safe and Sustainable by Design Framework: the ANALYST Project

Manuela D'Eusanio, Federica Silveri, Luigia Petti

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The European Green Deal aims to translate the Sustainable Development Goals (SDGs) into concrete actions to achieve a climate-neutral, sustainable and circular Europe by 2050. Pollution, a major driver of planetary crises, is central to the European Chemical Strategy (CSS) and the Zero Pollution Action Plan, which address the harmful effects of chemical on human health and the environment. Safe and Sustainable by Design (SSbD) aims to minimise exposure to harmful substances and promote safer alternatives, including bio-based chemicals and advanced materials. The ANALYST project, funded by Horizon Europe, aims to define and validate a comprehensive approach to assessing social, economic, environmental, and health impacts of chemicals, aligning with the SSbD framework. The project pursues three key innovations: 1) ANALYST-Box: Developing robust methodologies to evaluate impacts across the plastic value chain, including health, environmental, social, and economic aspects; 2) ANALYST-Digi: Creating an open-access platform with a multi-criteria decision-making support tool and a FAIR database to aid decision-making and support replicability pathways; 3) ANALYST-T-Pack: Implementing a demonstration and validation program with industries in the polyvinyl chloride (PVC) value chain. The SSbD framework developed by the Joint Research Centre, promotes the use of Life Cycle Thinking methodologies, suggesting that for social sustainability (Step 5 of SSbD), the Guidelines for Social LCA (UNEP, 2020) and the Methodological Sheet for S-LCA (UNEP, 2021) shall be followed. Although this phase is optional, it is critical for achieving a fully holistic sustainability assessment. Additionally, the new ISO 14075:2024 standard for Social LCA, released in October 2024, will be incorporated into the integrated approach by the ANALYST project to define social criteria for the PVC value chain. As of Month 12 of the project, the focus is on conceptualizing the ANALYST-Box, aiming to support industries and policymakers in making informed decisions within the PVC

value chain.

Social Sustainability of Nuclear Fusion Energy: A Multi-Regional Input-Output Analysis

Misa Iwamoto[1], Takuya Shimamura[1], Alexander Ryota Keeley[1], Daikichi Seki[1], Shunsuke Managi[1], Shutaro Takeda[2]

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Nuclear fusion energy is clean, safe, and produced from the most abundant fuel, hydrogen atoms found in seawater. It is one of the new power generation methods expected to become a reality by 2040 as humanity's ultimate energy source. However, achieving commercialization requires prior assessment of environmental, economic, and social aspects, but the social aspect has not been sufficiently investigated. This study aims to identify social risks in the supply chain of fusion power plant construction and compares these risks with existing power generation systems, offering insights into the policies needed for successful fusion power deployment.

To estimate social risks, this study employed an extended input-output analysis based on the framework proposed by Leontief et al., expressed as E = e x (1-Z)^-1 x Y. Eora Global Supply Chain Database-Full Table (reference year: 2022, 189 countries, 14,839 sectors) was used and integrated it with social risk data from the Social Hotspots Database. For the 10 existing power sources data were obtained from the UK Government's Electricity Generation Costs 2023. For fusion power plant data with a 1 GWe was derived from ARIES-ST construction cost by Najmabadi (1992). All costs were adjusted to 2024 prices, accounting for inflation.

The results showed that the risk of labor-related human rights violations during the construction of fusion power plants in the UK was 13.0 Risk Hours/MWh, ranking fourth lowest among the 11 power sources analyzed. The power source with the lowest human rights risk was onshore wind (4.1 Risk Hours/MWh), while the highest risk was biomass power generation (32.8 Risk Hours/MWh).

This indicates that fusion energy has favorable characteristics compared to existing energy sources, also from the social aspect of the supply chain. Such estimates are essential in supporting nuclear fusion energy development, which requires extensive research and development costs.

Social Impacts of Semiconductor's Global Supply Chains: Hotspot Analyses for the Materials Used by the Manufacturers in Taiwan.

Afifah Raudloh Annimah[1,4], Pi-Cheng Chen[1,2,3]

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Electronic component manufacturing contributes the highest GDP for Taiwan, underlining the significant role for the nation. The manufacturing of electronics requires a large variety of materials and components imported from different countries in the supply chains. These demands are the driving forces for overseas suppliers associated with different levels of social impact on many social issues. However, the use of Life Cycle Assessment in industries, particularly when integrating social factors within supply chain networks, remains underexplored. This study investigates the integration of Social Life Cycle Assessment into Taiwan's supply chains, specifically focusing on the semiconductor industry. By utilizing sectoral-level data on industrial raw materials and trade import values, this study identifies key social impacts associated with global suppliers. Using SimaPro with Social Hotspot Database, several social risks in the supply chains such as labor intensity were assessed by mapping input materials to the social impact along the foreign

and domestic supply chain. Key findings reveal that the highest social impact arises from the other process Integrated Circuits (including chips), primarily due to their significant value chain and contribution to the electronic manufacturing sector. Notably, the material of other semiconductor manufacturing components ranked the second highest in impact due to its corresponding social risk with democracy and freedom of speech and occupational injuries and fatalities. More than half of the impacts stem from very high-risk where overall risk related to democracy and freedom of speech, highlighting critical social challenges in semiconductor production. These findings underscore the need for social impact mitigation strategies, focused in governance, health and safety, and labor and decent work as areas of priority. While the semiconductor industry served as a subject of this case study, the methodology can be applied to assess the social impact of other countries that also have potential to expand their IC manufacturing.

Unlocking the Social Dimension: Requirements to Assess Social Impacts of Energy Storage Systems

Svenja Weber-Harmann[1], Kira Fischer[1], Marie Krug[1], Dustin Jürgens[1], Nikolas Dilger[1], Sabrina Zellmer[1,2], Christoph Herrmann[1,3]

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As energy storage systems become a cornerstone of sustainable development, examining their impacts across the three dimensions environment, economy and society are crucial. While most studies focus on environmental and economic impacts, social impacts are frequently overlooked. In light of the dynamics of the supply chain and the newly introduced Supply Chain Act, understanding the social dimension is becoming increasingly relevant.

The aim of this study is to outline the requirements for integrating the social dimension into an LCA study of an energy storage system using social life cycle assessment (S-LCA). A systematic review has demonstrated that the life cycle phases of raw material extraction and production are of particular interest in the domain of energy storage systems. The stakeholder group of the local community must be given particular consideration, especially with regard to the mining activities of the critical raw materials. The Product Social Impact Life Cycle Assessment (PSILCA) database has been identified as a promising resource, yet it is utilized in only a limited number of studies to date. In order to ascertain the usability of this database in the field of energy storage systems, PSILCA will be incorporated into the study.

Based on these findings, available data, e.g. from databases and literature, is researched and then methodically evaluated in terms of data quality and usability. The integration of an S-LCA into an LCA tool is enabled by the elaboration and presentation of requirements in a catalogue. The findings will be considered during the calculation of social impacts in the case study of a Li-ion battery.

The results will assist LCA practitioners in further developing the methodology of S-LCA and improving the measurement of social aspects of energy storage systems. Moreover, the identified hotspots can be used by companies and organizations to enhance the social performance.

Product-specific social life cycle assessment of bus transport from hydrogen production to hydrogen use

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In mobility, there is a notable shift from fossil fuels to sustainable fuels, driven by growing public awareness on sustainability and the need to secure Earth's future as a safe haven. Mobility-relevant emerging technologies such as those across the life cycle of hydrogen and biofuels are expected to play a key role in this transition. In order to drive this transition effectively, it is essential to develop these technologies along sustainable pathways. In this context, most research has overlooked social assessments in mobility case studies. Given this gap, the present work conducts a social life cycle assessment (S-LCA) of a hydrogen bus. As a case study, a hydrogen fuel cell bus and its value chain were analysed using the default indicators set in recent S-LCA initiatives specifically focused on hydrogen systems. The system under study encompasses three subsystems: bus transport service, hydrogen fuel cell bus, and hydrogen refuelling station with onsite electricity and hydrogen production. Overall, it includes a total of 70 plants, making it a complex supply chain. The results at the subsystem level reveal three distinct behaviours depending on the social indicators in consideration. In the first one, bus transport service exhibits complete dominance. The second behaviour shows a proportional contribution from all three subsystems. In contrast, the third behaviour highlights dominance of hydrogen fuel cell bus and hydrogen refuelling station subsystems. The S-LCA results aid in identifying social hotspots, while emphasising the necessity of automation to manage the complexity of the supply chains typically involved in product-specific S-LCA. This work has been carried out in the context of the HYPOP project, which is supported by the Clean Hydrogen Partnership and its members. HYPOP is funded by the European Union (Grant Agreement No 101111933).

Combine or stand-alone: S-LCA and social acceptance for decision making

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Integrating social impacts next to economic and environmental considerations into decision making procedures is tremendously important for companies because they bear a moral and societal responsibility. This is not only requested from the public, but also by political frameworks e.g., the corporate sustainability reporting directive (CSRD) or the corporate sustainability due diligence directive (CSDDD).

Social Life Cycle Assessment (S-LCA), as one out of three parts of Life Cycle Sustainability Assessment (LCSA), provides insights into social impacts of products along their life cycle and therefore, the methodology offers the possibility to support decision making procedures in the industry.

Another crucial factor for decision making in the industry is the social acceptance of products or technologies and manufacturing processes associated with them. The inclusion of social acceptance is especially meaningful during the development phase where expectations and needs of different stakeholders should be met to foster a successful market integration.

The question is raised whether there are concepts to combine S-LCA and social acceptance. A first literature review shows that authors of S-LCA based literature state the need to take social acceptance into account, while only a few provide approaches to do so e.g. by creating new impact categories, subcategories or indicators addressing social acceptance. Even though a definition of "social acceptance" is rarely found, results of S-LCA are seen as an empowerment for social acceptance. In contrast, scientists in the acceptance research field raise the point that more knowledge can, in some cases, lead to less social acceptance.

This prompts the need for additional investigations: Does the combination really provide benefits? Could the informative value be higher by a stand-alone assessment? By conducting a more in-depth analysis of the literature in addition to own elaborations, this will be contextualized for decision making in industries.

Preliminary S-LCA assessment of ViSS project bioplastic solution

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ViSS EU funded project (101081931) aims at producing bioplastics from food industry by-products (candies, poultry, vegetable and fruits) within a circular and safe and sustainable by design (SSbD) approach. ViSS SSbD framework sets a series of principles and methods to optimize the safety and the sustainability of the new bioplastic solutions, filling the gaps of the existing frameworks and methodologies to do so. In particular, the focus of this abstract is to provide a robust for the social dimension of sustainability. Given the actual TRL of ViSS solutions (TRL 5-6) the Social Life Cycle Analysis (SLCA) follows an intermediate assessment that has been proposed based on existing standards and guidelines and complemented by a participatory methodology involving the different stakeholders of the value chain and experts on different interdisciplinary fields. As a result, 24 out of 31 social aspects are assessed using 32 indicators. In addition, 5 consensus-based social sustainability principles are proposed for the first time within the SSbD approach: health, influence, competence, impartiality and meaning making. For the SLCA we follow a Social Organization Life Cycle Analysis (So-LCA) combining qualitative-quantitative approaches as they provide the opportunity to address SLCA requirements with the available data. The benchmarks used in the assessment are based on national figures as the value chain is in different Spain locations. For these benchmarks we have reviewed a series of sources, mostly national statistics, pertinent reports and national regulation. The preliminary results of this initial screening of SLCA assessments will be presented, enabling the assessment of ViSS value chain performance in comparison to the proposed benchmarks. This approach contributes to decision-making in the industry as it proposes principles and methodologies to identify options that are more socially sustainable, while contributing to an intuitive and empowering transformation.

Adapting Social Life Cycle Assessment Methodology for Sustainability in Informal Economies

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The informal economy plays a critical role in sustaining livelihoods, particularly in agricultural and fishing sector. Workers in this sector are most exposed to informality, with informal employment rate of 91% globally, 92% in low- and middle-income countries and 46% in high-income countries. However, assessing the social sustainability of this informal sector poses unique challenges due to its unstructured nature and lack of formalized systems. Current Social Life Cycle Assessment (S-LCA) methodologies (UNEP-SETAC, PSIA) are predominantly designed for the formal economy with standardized practices. These frameworks often fail to capture the nuances of informal economic activities, such as community-based resource management and subsistence-oriented production. This gap results in social impact categories that are misaligned or irrelevant when applied to informal sectors, limiting the efficacy of S-LCA in supporting inclusive sustainable transitions.

This study addresses this critical gap by exploring how to adapt, modify and create new S-LCA impact (sub) categories tailored to the informal economy in agriculture and fishing sector. Key challenges include lack of comprehensive data, the heterogeneity of informal activities, and socio-economic complexities such as inequitable value distribution, social justice, and local economic retention. A mixed-method approach is adopted, which integrates participatory stakeholder engagement and context-specific calibration of existing social impact (sub)categories.

By bridging this methodological divide, this study will enhance the applicability and relevance of S-LCA for the informal economy and provide a more comprehensive understanding of the social impact of informal activities, promoting equitable value generation, distribution, and local economic retention. This study is particularly significant for advancing sustainability transitions in agriculture and fishing sector where informal systems dominate, offering a model for inclusive social impact assessment globally.

Enhancing Social Life Cycle Assessments: The role of Social Hotspots Database (SHDB) Impact Assessment Approaches.

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Version 6 (V6) of the Social Hotspot Database (SHDB) now integrates the latest Global Trade Analysis Project (GTAP 11) input-output data, expands sectoral coverage to 65 economic sectors, and features updated worker-hour and wage models. These upgrades are meant to deliver finer granularity and more robust social hotspot detection across global supply chains. This study investigates how SHDB V6 together with its associated life-cycle impact assessment (LCIA) methods and normalisation features-advances contemporary social risk assessment by improving data resolution, indicator relevance, and result interpretability.

This has been achieved by creating a plausible inventory and using the SHDB in the SimaPro software to perform a Social Life Cycle Assessment (SLCA) of a hypothetical case study of-production of 1000 ton of blue hydrogen at a plant-unit based in USA followed by an integration with Carbon Capture and Storage (CCS). The aim was to explore how emerging industries and novel technologies can be systematically addressed for their social impacts thus contributing to more comprehensive SLCAs. With the global hydrogen demand experiencing significant growth in recent years, the study aims to comprehend how SHDB's LCIA methods can contribute to identifying the social risks pertaining to the ever-advancing energy technology sector. The study assessed the social impacts associated to blue hydrogen production along with successfully identifying the social hotspots in the supply chain.

The findings highlight the database's potential to support practitioners and researchers in pinpointing high-risk sectors and guiding evidence-based social sustainability strategies.

Water footprint analysis of biofuel value chains

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Shell International

Understanding the resilience of value chains to water scarcity risks is crucial for informed project decisions and anticipating changes in the costs and availability of feedstock and water supplies. Larger companies in Europe are increasingly assessing the water footprint of their supply chains to address all water-related risks. Following the Corporate Sustainability Reporting Directive (CSRD) and the Corporate Sustainability Due Diligence Directive (CSDDD), companies with significant EU turnover must disclose water use of their supply chains from 2027.

The AWARE water footprint methodology, endorsed by European Sustainability Reporting Standards, was used to assess water risks across several biofuel value chains. Significant variations in water consumption among different pathways were observed due to difference in geographic coverage and irrigation practices. It was observed that existing LCA databases exhibit both high uncertainty in water inventory data and lack of regionalized characterization factors. There was also a lack of clear requirements for the water inventory data that should be used for AWARE impact assessment. As a result, this limits the implementation of data collection and water management optimizations. Overall, these issues cause the industry interpreting rules differently, making comparisons among projects difficult, and complicating decision-making.

Therefore, we propose a risk matrix that incorporates water consumption and local water scarcity indices as a preliminary high-level screening tool to facilitate a risk-based approach in identifying mitigations for high-risk value chains. Additionally, we present recommendations for the development of a biofuel sector specific guidance that includes considerations for corporate organizations when applying water footprint methodology, harmonizing calculation approaches, as well as improving data quality and communication along the supply chain.

Challenges in upscaling perovskite photovoltaics at low TRL from an LCA perspective

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Perovskite photovoltaics has been a prominent topic of interest for photovoltaics researchers. When compared to other PV systems, on a lab scale, perovskite PV has shown clear benefits over thickness, lower production costs, and greater efficiency. Perovskite PV has been shown to be stable over thousands of hours, and researchers claim that its efficiency can reach up to 25%. Due to its lightweight properties, perovskite PV can have many applications in different sectors, including aerospace and automobile.

Regardless of these advancements, there are significant challenges to the large-scale production of perovskite PVs, particularly from the perspective of life cycle assessment (LCA). The main challenges hindering the LCA study are inadequate inventory data & data quality, lack of tailored LCA methodology, and substantial challenges in scaling up. This study aims to demonstrate the method for scaling laboratory-scale data to industrial-scale data, with a particular focus on material and energy consumption associated with deposition techniques. By bridging the gap between small-scale experimental results and large-scale manufacturing requirements, the analysis will provide insights into resource efficiency and energy demands, laying the groundwork for more accurate and reliable life cycle assessments of emerging photovoltaic technologies.

This research performs a comprehensive attributional LCA of perovskite PV from cradle to grave. The primary data were gathered from project partners and supplemented by data sets from ecoinvent v3.9.1, which act as secondary data. The study complied with ISO 14040/44, PEFCR, and IEA guidelines; the study also harmonized with other PV projects across Europe to ensure methodological rigor. Sensitivity and uncertainty analyses are done to evaluate the integrity of the data. The results portray the environmental effects of perovskite PV in the different stages of the life cycle and different impact categories.

Harnessing Variable Renewable Energy using Thermal Energy Storage: An Exploration Towards Optimal Energy Production Strategy in the Japanese Beet Sugar Industry

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The beet sugar production industry, a vital economic sector in the Hokkaido region responsible for approximately 80% of Japan's domestic sugar production, faces an urgent need to reduce greenhouse gas (GHG) emissions and transition toward sustainable practices. Integrating renewable energy sources such as solar, wind, and biomass, is essential to achieving these goals. Unlike sugarcane-derived sugar production, which utilizes bagasse—a key byproduct—as a dispatchable biomass fuel, beet sugar production continues to rely heavily on coal. Although beet pulp, a primary byproduct of beet sugar production, holds potential as a biomass fuel, it is already extensively used as animal feed in the Hokkaido region. Consequently, exploring the use of variable renewable energy (VRE), such as solar and wind, is critical to improving the sustainability of beet sugar production.

A significant challenge in incorporating VRE into industrial processes is its variability, which can compromise operational stability. To address this issue, this study focuses on the use of thermal energy storage (TES) systems, which store VRE as heat and regenerate power as needed. Sensible heat storage TES, such as systems utilizing molten salt, is commonly applied in concentrated solar power generation. However, not all energy stored in TES can be regenerated as power; a portion must be used as thermal energy, typically in the form of low-temperature, low-pressure steam. Given the high heat demand in beet sugar production processes, including evaporation and crystallization, integrating VRE with TES presents a promising solu-

tion for enhancing sustainability.

This study examined the potential of integrating solar power as a VRE source with TES to improve the sustainability of beet sugar production. Several energy production scenarios were developed, including a combined coal boiler scenario and an electrification scenario, and their associated GHG emissions were quantified to determine the most suitable energy production strategy under various conditions.

Life Cycle Sustainability Assessment of an emerging renewable electricity technology: CATCHER humidity-to-electricity converter

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The European Union is actively advancing its renewable energy capacity as a central effort towards its climate neutrality goals and a greater energy independence. The CATCHER project aims to strengthen the EU's renewable energy market through the development of an innovative nanomaterial-based technology that converts atmospheric humidity into electricity.

CATCHER builds upon previous research from the HUNTER project, which developed a test prototype at TRL 3-4. The device leverages the functional heterojunction effect to enable a chain of physicochemical, physical, and electrophysical processes on the interface of a nanostructured oxide material, specifically a zirconium oxide surface, triggered by the adsorption of water molecules from the surrounding atmosphere. A one cubic meter converter has the capacity to power a 100-200 m2 household.

The project is expected to reach full-scale production by 2029, with a planned manufacturing capacity of 750 modules per month, each capable of producing 420 watts per cubic meter. When functioning continuously, a standard-size device will generate 10 kWh per day.

As part of the roadmap to evaluate the feasibility of the devices, we are conducting an LCSA following the ORIENTING methodology. This framework integrates LCA, S-LCA, and LCC along with product circularity and raw material criticality indicators. The assessment will provide a holistic view of the technology's global sustainability performance by identifying, quantifying, and comparing its environmental, social, and economic impacts. Its main pillar is a combination of an ex-ante LCA of the prototype and a prospective LCA that evaluates the impacts of scaling up the technology.

The LCSA results will contribute to a wider integrated multicriteria study of the benefits, costs, and risks of the deployment of the technology, and help compare the solution to other existing renewable energy sources, offering insights to guide the development process and inform future decision-making.

Multi-criteria decision support for more sustainable fuel wood supply

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Timber is a globally relevant renewable energy source that plays a key role in reducing carbon footprints and transitioning to more sustainable energy systems. However, its benefits are maximized only when accompanied by responsible forestry practices and technological innovation. The supply of wood can be carried out in different ways. The selection of the most suitable timber supply system requires experience and can be facilitated by the use of a multi-criteria decision support (MCDS) system.

A screening of various LCA studies about wood supply (from tree breeding to transportation of the harvested timber to the plant) has shown that the methodological approach and data quality vary greatly depending on the study. The creation of a standardized framework and the development of recommendations are

important objectives for a more efficient and harmonized application of LCA in the forestry sector.

More than 30 different criteria have been identified to assess the sustainability of forest operations. There are many relevant stakeholders to be involved in finding the best solution in a multi-actor-approach. We conducted a survey to determine the weighting of the criteria with regard to profession, tasks, age, work experience of the respondents. A computer-based decision support tool was developed to assist stakeholders in identifying the most suitable fuel wood supply chain to meet their needs. Users can specify site, stand and environment data and technology parameters, and set their individual preferences for balance between the criteria. The overall utility of various treatment alternatives is calculated by an additive utility model and presented via on-screen graphs and tables. It could be shown that the combination of LCA and MCDS makes it possible to consider all three pillars of sustainability, i.e. economy, society and environment, as well as the needs of stakeholders, which significantly increases the relevance and acceptance of the developed model.

Evaluation of the environmental and economic impacts of a demonstrator facility for the production, storage and reconversion of hydrogen into electricity

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The transformation of the energy system towards a resource-efficient and low-emission energy supply is one of the central challenges of the energy transition. The utilization of renewable energy sources plays a crucial role in sustainably meeting the rising energy demand while reducing dependence on fossil fuels. However, a significant obstacle is the storage of volatile energy quantities, which requires innovative and efficient energy storage technologies to balance the discrepancy between energy generation and demand. Against this backdrop, an innovative hydrogen demonstrator facility is being established, which is the focus of this investigation. This facility comprises an electrolyzer for hydrogen production, a storage system for intermediate hydrogen storage, and a fuel cell for reconversion to electricity. The facility is operated using surplus electricity from a photovoltaic system. This configuration allows for the complete integration of hydrogen technology into industrial processes. The aim of this study is to conduct a comprehensive environmental and economic assessment regarding the production and operation of the demonstrator facility. The environmental and economic impacts of the hydrogen produced and reconverted to electricity will be compared to the procurement of electricity from the German power grid. A comparative life cycle assessment and a life cycle cost analysis with a cradle-to-gate approach have been conducted.

Semi-automated monitoring for scientific data management on energy transition

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As the energy transition accelerates, the rapid access to reliable and relevant information from scientific literature, patents, and grey literature has become crucial. This project aims to develop a semi-automated monitoring system designed to collect, analyze, and organize data related to materials used in energy transition technologies, which can also serve as data sources for life cycle inventories (LCI).

By leveraging advanced tools such as scraping, natural language processing, and artificial intelligence, the system seeks to enable the automatic extraction and classification of key information from diverse sources. These data will be consolidated into an interactive platform to streamline analysis, research, and deci-

sion-making.

This initiative aims to optimize the utilization of available resources, identify innovative materials, and enhance research and development capabilities in strategic sectors such as renewable energy, energy storage, and low-carbon technologies.

MAGNUM: Revolutionizing Water Footprint Assessment in the Tourist Sector for a Smart Water Management

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Water scarcity is an escalating global challenge, and the tourism sector, particularly hotels, is under growing pressure to optimize water management practices. While carbon footprinting has achieved widespread adoption, water footprint assessment, especially encompassing both direct and indirect water use, remains largely unknown despite its critical role in promoting sustainability. The MAGNUM project addresses this gap by developing an innovative tool that automates the calculation of a hotel's water footprint and integrates Artificial Intelligence (AI) and Building Information Modeling (BIM), the platform provides detailed, real-time analysis of direct water use (e.g., water consumed within hotel operations such as guest rooms, kitchens, and laundry facilities) and indirect water use (e.g., water embedded in the production of goods and services, including food and cleaning supplies). This assessment covers blue, green, and grey water categories and aligns with methodologies established by the Water Footprint Network and ISO 14046.

The MAGNUM platform simplifies the calculation process, enabling detailed visualization of water consumption patterns and leveraging AI for anomaly detection. By identifying water footprint hotspots, the tool supports the development of targeted strategies to reduce water usage, addressing both guest consumption and operational practices by hotel staff, fostering both operational cost savings and sustainability.

The focus of this study will be to highlight the advantages of technologies like MAGNUM in the context of water management. By automating the calculation of water footprints and making these insights more accessible, the platform removes barriers to implementing sustainable water practices, demonstrating the significant impact these tools can have on improving water use efficiency in hotels and supporting the implementation of effective actions. Ultimately, the study aims to showcase how such technologies can revolutionize water-intensive companies and contribute to global water conservation efforts.

Introduction to Taiwan's Indigenous LCA Database and Software DoITPro

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A complete Life Cycle Assessment (LCA) typically relies on LCA software and its embedded methodologies and databases for evaluation. Currently, there are numerous LCA software programs available worldwide, and the Industrial Technology Research Institute of Taiwan has also developed an LCA software called DoITPro. DoITPro is utilized for internal research and has guided over a hundred domestic companies in conducting LCA and carbon footprint analysis, while establishing an indigenous database.

LCA adheres to the principles and framework of ISO 14040 to assess environmental impacts, and using methodologies, classifies and characterizes environmental impact indicators, resulting in the generation of numerical values for each environmental impact indicator. The methodologies currently followed by DoITPro primarily include IPCC 2021 GWP100, EF3.1, and CML-IA (version 4.4). The industries involved in the database built into DoITPro encompass: energy resources, transportation services, electrical and electronic components, mechanical components, rubber, plastics, packaging materials, metals, and chemicals.

The pros and cons of using Artificial Intelligence in LCA: a review of 34 LCA-based tools

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The world is becoming increasingly dynamic, and, as a result, decision-making processes within companies have had to accelerate to keep up with this pace. The importance of tools that reconcile environmental issues with the speed of response required by stakeholders emerges - whether in selecting a product with better environmental performance (as in the case of consumers) or in defining a material with a lower environmental burden (as in the case of companies). This paper revised 34 Life Cycle Assessment (LCA)-based tools in the context of integrating them into Artificial Intelligence (AI) features. Several tools were found catering to different sectors and specific environmental characteristics. These tools demonstrate applicability in sectors such as agriculture (14), multisectoral (4), industries (3), construction (2), packaging (2), transport (2), end-of-life (2) and others (5) serving as essential instruments for decision-making based on environmental data. However, it is crucial to emphasize that they do not replace comprehensive LCA studies but instead facilitate analyses and provide robust support for more informed decisions. Finally, the possibility of integrating these tools with Artificial Intelligence (AI) systems stands out for 6 tools, as they are available for download in Excel format, they can therefore be easily integrated with AI using Python libraries. Such integration, by exploring synergies between AI and be LCA tools, represents a promising strategy and constitutes the central focus of this work.

Bridging the gap: Developing a LCA methodology for software at Siemens

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With the increasing focus on sustainability, LCA has established itself as an important tool for creating transparency and as a basis for reducing environmental impacts. To date, the method has mainly been used for physical products and provides detailed information on the sources of emissions over the life cycle.

As digitalization progresses, the share of revenue generated by software is growing and so are the associated emissions. The environmental impact transparency through LCAs plays a fundamental role in the DEGREE framework, which defines clear goals and actions for Siemens sustainability ambitions. For these reasons, Siemens has taken the initiative and is researching the transfer of the LCA method to software.

When it comes to sustainable software, the Software Carbon Intensity Specification (ISO/IEC 21031:2024) is currently the most important reference. Compared to an LCA, it is a score rather than a total and therefore only a one-dimensional approach. To continue to reduce our emissions, it is crucial to understand and evaluate our software throughout its entire life cycle.

We are currently developing a LCA methodology for software based on pilot projects. Initial results show that it is difficult to make general statements about the main emission sources of a software application. This is because software architectures, functionalities and user behaviors are highly specific.

During the development phase, building energy consumption and business travel can have a big impact. During the use phase, energy consumption of end-user devices, data centres, and data transmission networks play a crucial role. Ultimately, however, the level of emissions and the influence of the single components depend primarily on the extent to which the software scales. And then there are also the embodied emissions...

We are pleased to present our methodology and look forward to exciting discussions!

Systematic review of the integration of life cycle assessment and blockchain

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Blockchain offers substantial potential to advance life cycle assessment (LCA) by enhancing traceability, transparency, and accuracy of inventory data and assessment results. In recent years, the integration of blockchain and LCA has attracted growing research interest. This study aims to provide a comprehensive and up-to-date analysis of the current state of research in this emerging field. A systematic review of published articles on the integration of blockchain and LCA is conducted, focusing on publications indexed so far in Web of Science and SCOPUS. A total of 31 articles are identified and subjected to bibliometric analysis. The study further examines and synthesizes the data for the detailed analysis of key themes, including benefits, barriers, frameworks and models, and case studies. The results reveal that research on blockchain-LCA integration remains in its infancy. While many studies highlight the potential benefits of integration across various stages of the LCA process, significant challenges persist, including technical, organizational, and system-related barriers. Notably, only a small number of studies have developed frameworks, models, or presented case studies, with a significant scarcity of empirical data-based case studies. Based on these results, this study presents a novel and practical generic framework designed to support the blockchain-LCA integration. The applicability of the framework is demonstrated through the potential application of the cotton clothing supply chain. Additionally, the study provides suggestions to foster further development of blockchain-LCA integration and offers implications for businesses, policymakers, and the scientific community to support progress in this field.

Challenges in Aligning an Emerging Chemical Recycling Process with the Sustainability Requirements of the EU Taxonomy

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The transition to a sustainable circular economy requires innovative recycling methods that align with both environmental and evolving regulatory demands. A critical regulatory instrument in this context is the EU taxonomy, which places sustainability criteria, e.g., on the carbon footprint of recycled plastics. Although there are many approaches to the ecological assessment of chemical recycling, a reliable evaluation scheme for taxonomy is still lacking.

Moreover, the EU taxonomy presents challenges for sustainability assessments due to its inherent flexibility and lack of precise guidelines. This can lead to diverse interpretations regarding key methodological aspects such as system boundaries or burden allocation, resulting in inconsistencies in how life cycle assessments are conducted, reducing their comparability and transparency.

The aim is to uncover critical gaps that may impact the capability of these assessments by identifying and analyzing the challenges and weaknesses that arise when aligning them with taxonomy requirements. A catalytic chemical recycling process which is currently under development serves as a case study to examine the broader challenges and opportunities associated with evaluating and implementing innovative technologies under the EU taxonomy.

The final goal of the case study is to evaluate the environmental performance of the recycling process, covering the entire value chain from waste collection to purified products. A key element of the approach is scenario modelling, which incorporates various process configurations to explore the environmental trade-offs and optimization potentials.

While still in an early phase, the project highlights the complexity of conducting taxonomy-compliant sustainability assessments for innovative recycling processes. By focusing on methodological flexibility, regulatory alignment, and practical implementation challenges, this study contributes to the ongoing dialogue on

advancing the sustainable transition of polymer recycling systems.

This work was supported by the German Federal Ministry of Education and Research (BMBF) as part of the pool-in-loop-UP project (033R388C).

Accelerating product and service carbon footprint estimations using a data science approach

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LCA methodologies are well established as the gold standard for evaluating sustainability metrics across industries, particularly for greenhouse gas emissions, and have become integral to demonstrating compliance to standards and establishing benchmarks. However, in some industries, such as the provision of upstream oil & gas engineering services, a large variety of complex products and solutions are provided across multiple geographies, and completing LCAs is challenging due to quantity of information required and the large variability and inconsistency of input parameters for emissions calculations across the various lifecycle stages. There is a risk that sustainability efforts get bogged by performing so many LCAs, at the expense of implementing actions that could reduce emissions footprints.

To address this, we propose an approach that derives product and service carbon footprint for the relevant functional unit (such as operation, year or delivery) by leveraging existing corporate data sources, machine learning and artificial intelligence. Specifically, our example uses a corporate greenhouse gas inventory together with revenue and associated product and service parameters that are recorded in delivering services to customers. These datasets are merged, after which we use data-science methods to explore and iterate relationships among product & service parameters, revenue and emissions for specific emissions scopes, scope categories, countries and business units. The result is set of over ~561,000 individual emissions factors corresponding to all possible combinations. Using an artificial intelligence approach, these emissions factors can be further refined down to the level of individual products and services.

The method has been validated against specific use cases where domain specific bottom-up calculators are available and is a likely approach for deriving meaningful and actionable product carbon footprint and service carbon footprint estimations for a large variety of products and services in a fraction of the time needed for conventional LCA analysis.

Accelerating Life Cycle Assessment with Generative AI: A Retrieval-Augmented Approach to Enhance Data Access

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Accessing relevant information within Life Cycle Assessment (LCA) literature remains a complex, and time-consuming task due to the high volume and diversity of documents for LCA assessments. This challenge highlights the need for advanced tools, which are capable of efficient information retrieval. In response, we developed a chatbot based on a Retrieval-Augmented Generation (RAG) technique and adapted it into the LCA domain. This approach mainly runs through four stages: Data indexing, Retrieval, Augmentation, and Generation. Initially, we gather a comprehensive dataset of LCA documents and journals from diverse, authoritative sources. To index the data, we extract the information as the sentences from available documents, tokenize each sentence, and embed these tokens to store into a vector database for optimal data retrieval. A Large Language Model (LLM) was then deployed to allow for context-aware responses, providing users to access relevant content according to their query. The model's accuracy is evaluated using the RAGAS metrics (Context Precision, Context Recall, Response Relevancy, Faithfulness), which confirms the LLM's ability to retrieve the LCA information. The process is implemented within the KNIME

low-code/no-code platform, and our approach has shown the possibility to adapt Generative AI into the LCA domain. This advancement not only addresses critical accessibility gaps within the LCA field but also demonstrates the potential of AI tools to accelerate research processes, ensuring that LCA practitioners can keep pace with the evolving demands of sustainability assessments.

The Revolution of Sustainability in Industry: The Application of Smart Systems to Decision-Making Based on Life Cycle Assessment

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In recent years, the integration of Smart Systems, such as Artificial Intelligence (AI) into industrial sustainability practices has become a pivotal aspect of advancing Life Cycle Assessment (LCA) methodologies. This research investigates the potential of Smart Systems in refining decision-making processes predicated on LCA, thereby delivering improved capacities in sustainability assessment, resource optimization, and mitigation of environmental impacts. A systematic review of relevant literature published between 2014 and 2024 was conducted to analyze the current state of AI integration in LCA. The findings reveal a promising future for AI in this domain, with several key applications identified. AI algorithms possess the capability to scrutinize intricate data sets and forecast prospective outcomes throughout the entirety of the product life cycle, thus empowering industries to render judicious decisions pertaining to design, production, and end-of-life management. Another significant advantage is the adeptness at automating and optimizing data analysis, a task that conventionally necessitates considerable temporal and intellectual resources. ML models also have the potential to enhance the precision of impact assessments by identifying patterns and correlations within extensive datasets that may be neglected by traditional methodologies. Furthermore, AI can assist industries in rapidly acclimatizing to regulatory shifts and market exigencies by furnishing real-time insights and predictive analytics. Despite the promising potential, the need for vast amounts of high-quality data poses a significant barrier, as does the challenge of seamlessly integrating AI models into existing industrial workflows. Additionally, the specialized skills required to operate and maintain AI-powered LCA systems create a potential skills gap. Data security and privacy concerns are paramount, especially in industries dealing with sensitive information. The integration of AI in LCA presents a substantial opportunity to improve sustainability practices and decision-making. However, careful consideration of challenges related to data availability, integration, skills development, and data security is crucial for successful implementation.

Preparing DPPs through Internal LCA Tools: How to extend the use of FDES configurators in the frame of the revised CPR

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The effective implementation of Digital Product Passports (DPPs) depends on accurate, transparent, and standardized environmental data throughout a product's lifecycle. To meet the Ecodesign for Sustainable Products Regulation (ESPR), industries must develop robust internal Life Cycle Assessment (LCA) tools.

Upcoming revisions to the construction product regulation will introduce significant changes:

1. Mandatory EPDs for CE-Marked Products: All construction products with CE marking will require Environmental Product Declarations (EPDs), leading to increased demand.
2. Factory-Specific EPDs: Grouping and averaging will no longer be allowed, necessitating declarations

tailored to each production site.

3. Streamlined EPD Verification: Faster processes will be vital to handle the increased workload.

Our approach leverages FDES configurators (French Environmental and Health Declaration for Construction Products) to simplify creating verified environmental data. These tools enable manufacturers to produce tailored LCA results and declarations for product variations, reducing time and complexity involved in producing DPP-compliant data. By automating data collection, calculation, and reporting processes, configurators enhance accuracy, ensure regulatory compliance, and scale efficiently across diverse product lines.

This study explores how FDES configurators can generate DPP-ready information in the construction sector. Key benefits include greater transparency, streamlined verification, and support for sustainable decision-making. Configurators also improve traceability by linking environmental data to specific product attributes, ensuring DPPs accurately reflect environmental impacts.

The presentation will highlight challenges in developing and deploying these tools, such as data standardization, supply chain integration, and adapting to evolving regulations. By adopting advanced LCA tools like FDES configurators, industries can prepare for DPP adoption, empowering stakeholders with reliable sustainability data and advancing the circular economy.

Effective analysis of engagement by financial institutions using LCA

Riku Isawa[1], **Masahiro Kato**[2], **Norihiro Itsubo**[1]

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As categorized in SCOPE 3, Category 15, "Investment," the implementation of investments and loans indirectly generates environmental impacts in the supply chain. Therefore, financial institutions are expected not only to incorporate climate change response into their own business strategies as operating companies, but also to play a role in providing support to the companies they invest in and finance to help them decarbonize. One of the key approaches is constructive dialogue (engagement) with companies to resolve environmental and social issues, and quantitative analysis based on LCA can be an important decision-making tool to take concrete corporate actions in order to appropriately recognize complex and intertwined issues. However, examples of LCA being used in engagement with companies to date have not yet been sufficiently systematized. Based on this background, this study aims to utilize the results of LCA analysis in engagement practices with companies to promote appropriate recognition of issues. In addition, by analyzing how companies have subsequently transformed, we aim to seek a framework to promote corporate transformation and enhance the effectiveness of engagement. We utilized the Multiregional Input-Output (MRIO) table for LCA analysis to comprehensively assess environmental impacts in global supply chains. In addition, financial information from annual securities reports was utilized as corporate data. In addition, financial information from annual reports was used as company data. The assessment targets were expanded mainly from material manufacturers, and impacts in climate change and land use were calculated for each SCOPE. In the future, engagement using actual LCA results will be conducted to confirm recognition and penetration of the issues and actions by companies. By analyzing, identifying, and improving key ESG issues from a life-cycle perspective, we aim to help companies solve environmental and social issues and increase their long-term corporate value.

Vanadium vs aqueous organic redox-mediated flow batteries: a comparative LCA study

2Israel Carreira-Barral, Jesús Ibáñez, Ana García-Moral, Rubén Rubio-Presa, Virginia Ruiz, Edgar Ventosa, Gonzalo Salazar, Sonia Martel-Martín

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Redox flow batteries (RFBs) are a versatile energy storage solution and a promising technology to face the transition from fossil to renewable energy. Among RFBs, the vanadium redox flow battery (VRFB) is the most common one, but if compared to the lithium-ion battery (LIB), VRFB is still at an early stage of development. Redox-mediated flow batteries (RMFBs) are another class of RFBs, characterised by the use of solid redox materials, called 'boosters', and solubilised redox species, named 'redox mediators', which store and carry the charge of the RMFB, respectively. RMFBs have a high energy density and recyclability, but little is known about their environmental performance throughout their lifecycle.

Both lithium and vanadium are considered critical raw materials (CRMs) in the European Union, which makes it urgent to find alternatives that do not rely on scarce resources and are friendlier from the environmental perspective. Herein a comparative LCA study between a conventional VRFB reported in the literature5 and a preliminary version of a RMFB designed in the 'MeBattery' project, the latter free of CRMs, is presented (Figure 1). A thorough analysis of the results shows that VRFB and RMFB could be environmentally competitive technologies, a promising outcome considering the low TRL of the designed RMFB.

Materials Scarcity in Prospective LCA for two different battery chemistries

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Sectorial electrification is a key strategy towards reducing greenhouse gas (GHG) emissions as the world tries to wean off fossil fuels in its path towards net zero. Electrification has been gaining impetus in the maritime industry, which contributes roughly 3% of the global GHG emissions. A possible route is by transitioning to battery propulsion thereby mitigating the environmental impact of maritime operations. Battery propulsion offers a cleaner alternative, eliminating direct emissions during operation and significantly reducing the carbon footprint of vessels. Additionally, advancements in battery technology, such as improved energy density and longer cycle life, make battery systems more viable for the energy demands of large ships. By adopting battery propulsion, the cruise industry can enhance its sustainability, comply with stringent international regulations, and meet the growing consumer demand for environmentally responsible travel options. This shift is crucial for the long-term viability of the industry and the protection of the oceans and atmosphere. Among the various battery chemistries available Lithium Iron Phosphate (LFP), and Sodium-ion Batteries (SIB) have emerged as promising candidates for maritime applications due to their distinct electrochemical properties and performance characteristics.

In this study we asses the life cycle impacts of LFP and SIB battery modules focusing on crustal scarcity indicators. SIB modules have a higher crustal scarcity impact due to their lower gravimetric density and cycle life, which affects material usage. However, the end-of-life phase shows greater material recovery benefits for SIB cell chemistry relative to LFP. The study underscores the importance of considering different end of life treatments and the uncertainties in recycling processes, which warrant further detailed analysis in future research.

Carbon footprint of Advanced biofuels from Microalgae CO2 conversion

CARLA BARTOLOME RODRIGO, Andrea Rodenas Garcia

ITENE, Spain

Europe commitment to decarbonisation has made notable progress in reducing CO2 and GHG emissions. However, projections indicate that the reduction in emissions is insufficient to meet the objectives of the European Green Deal's and its ambitious targets of a 55% reduction by 2030 and achieving carbon neutrality by 2050. Particularly, emissions from the transport sector have increased continuously (by 19% compared to 1990) against the trend of total emissions, exceeding the projected emission limit for 2030. Emissions, therefore, need to decrease two-thirds by 2050 in order to meet the 60% GHG emission reduction target of the 2011 Transport White Paper.

In order to decrease carbon emissions from the aviation and shipping sectors, liquid clean fuels must be developed and supplied at sufficient rates to meet airlines and shipping company's needs. The solution for these sectors, where electrification is complicated, is using biofuels, as they are considered carbon neutral. In this sense, FUELGAE project addresses industrial CO2 emissions by developing a novel model for producing advanced liquid fuels (ALF), utilizing microalgae as a promising solution for direct CO2 sequestration.

Microalgal biomass is increasingly recognized as a key renewable resource for sustainable aviation fuels (SAF) and other transportation biofuels within 3rd generation (3G) biorefineries, thanks to its capacity to produce lipids, polysaccharides and other biochemical macromolecules that can be converted and upgraded into fuels. FUELGAE will demonstrate the sustainability, neutrality and feasibility of the production of ALF from microalgae through Life Cycle Assessment and CML IA baseline methodology. Also, these results are compared to conventional fossil-based diesel, as well as biodiesel production from vegetable oils.

Sustainable Reed Biomass Utilization Strategies: A Life Cycle Assessment Case Study in Latvia

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This study explores the potential of common reed (Phragmites australis) to be used as a sustainable resource in the bioeconomy. Reed is considered an underutilized biomass and can be found extensively in Latvian wetlands, offering significant potential to be used in wide range of applications, such as bioenergy, construction, and packaging. Reed products can present unique opportunities for addressing climate change and ecosystem degradation. Reeds are growing on non-agricultural lands and are a renewable resource for replacing conventional materials with higher environmental footprints. The Life Cycle Assessment (LCA) is applied in this study to assess the environmental impacts of the commercial application of reeds. LCA is used as a tool for understanding the environmental trade-offs and benefits of reed utilization. By providing insights into greenhouse gas mitigation and carbon sequestration, the project supports informed decision-making for stakeholders aiming to balance resource use with environmental preservation. Modeling of scenarios is performed considering biomass availability in Latvia. The study aims to identify the most sustainable reed valorization strategies, considering circular economy principles and the socio-economic implications of reed-based products. The results of the study serve as a basis for drafting sustainability guidelines to assist stakeholders in integrating reed-based solutions into local and national sustainability frameworks. The study provides a foundation for encouraging the utilization of reed as a viable bioresource, supporting rural income diversification, reducing reliance on fossil fuels, and advancing Latvia's bioeconomy.

A Multi-Criteria Decision-Making tool to be used in Green and Circular Public Procurement

Nicolas Bertoldo1, Mette Alberg Mosgaard2, Anja Marie Bundgaard2, Giovanni Dotelli1

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Public procurement is a pivotal component of governmental activities and economic systems worldwide. In the European Union (EU), member states spend an average of 14% of their GDP on procuring goods and services. By selecting environmentally friendly and circular products, public authorities (PAs) can promote these solutions and reduce overall environmental burdens. This approach, known as Green Public Procurement (GPP), aims to achieve sustainability by prioritizing products and services with lower environmental impacts and long lifetimes. The EU is actively developing environmental and circular criteria for various product and service categories.

The objective of this study is to develop a methodology to support PAs in selecting the most circular and environmentally sustainable products and services in public procurement, through the adoption of e.g. EU GPP requirements. The main outcome of this work is a web application tool which can be integrated into the public procurement decision-making process. The tool allows a simple, transparent and reliable assessment of compliance with the designated criteria. It serves to facilitate an efficient comparison of different bids within the public procurement decision-making process. Moreover, the tool allows tenderers to provide necessary data and upload supporting documentation, enabling public authorities to efficiently evaluate bids against selected criteria. The comparison is then made considering whether the selected criteria are satisfied, and a preliminary ranking of the bids is made according to the compliance levels with the selected award criteria.

As a first implementation, the methodology considers the furniture category, taking into account the EU requirements, as well as specific defined criteria based on Life Cycle Thinking, focusing on circularity and environmental aspects.

By providing a standardized approach to GPP implementation, this study contributes to the broader EU objective of fostering a resource-efficient economy and stimulating demand for more sustainable goods and services.

Assessment of sustainability benefits using comparative LCA of recycled PET and virgin PET with a case study of fibers.

Karishma Sameer Tijoriwala, Harsha Reddy, Soumen Munshi, Anand Sharma, Pattaraporn Khamhongsa, Vishwesh Pavnaskar, Samrat Bose

Indorama Ventures PCL

PET is one of the most durable and cost-effective polymers used to produce consumer packaging and textiles. While being fully recyclable only a fraction of the post-consumer PET is given a second life. Improving this can help meet the growing demand of low carbon and durable clothing while mitigating PET waste.

IVL is actively recycling post-consumer PET since 2011, with a target of recycling 1.5 million tons annually by 2030. The recycled PET (rPET) is used to produce packaging grade plastic and fibers. An LCA study was conducted to compare the cradle to gate impact of fibers using virgin PET produced on site from fossil-based feedstock with recycled PET processed from waste PET bottles. In this case, the cut-off approach is applied to rPET. The study was conducted in accordance with ISO 14040/44 following reporting guidelines outlined by WBCSD and TfS.

Our findings reveal that the impacts of rPET fibers for most midpoint indicators is significantly lower compared to vPET fibers. GWP 100 years is reduced by 45%, while a 100% and 68% reduction in abiotic elemental and fossil depletion respectively is observed. The savings are due to major difference in raw materials.

Energy requirements are lower for rPET fibers by 48% due to lower requirement of thermal energy which is predominantly produced from coal. The freshwater consumption is higher for rPET fibers for cradle to gate. To mitigate the this, the site works actively to recycle water.

The quality and durability of fabric produced with rPET is at par with vPET and has the potential of replacing vPET in the textile industry with conscious consumption of water.

The study highlights, that recycling is not just a way to combat plastic waste, but also to lower the carbon footprint of textile products along with providing socio-economic benefits for local communities.

Session 2.13: Boosting LCM with AI, Machine Learning & Data Science Tools

Time: Thursday, 11/Sept/2025: 2:30pm - 4:00pm
Session Chair: Antonino Marvuglia, Luxembourg Institute of Science and Technology, Luxembourg
Session Chair: Peter Rudolf Hans Saling, BASF SE, Germany

Integrating Large Language Models into the In-Silico environmental assessment of new chemicals and materials for SSbD

Gustavo Larrea-Gallegos, Antonino Marvuglia

Luxembourg Institute of Science and Technology, Luxembourg

The introduction of the European Commission's "Safe and Sustainable-by-Design" framework represents a catalyst in the wide adoption of SSbD practices and it is a milestone in the transition towards more sustainable societal systems. This has spurred an increasing interest in displaying practical implementations of SSbD among policy makers, academia, and industry players, such as the chemical sector. As far as the sustainability part is concerned, conducting such a type of assessment at early stages of the design process is far from trivial, since the lack of data and the need of lengthy modeling pipelines challenge the adoption of this framework in a consistent way, hence the need for the creation of effective workflows and tools to fill this gap. This study proposes a novel modeling workflow that combines the power of Large Language Models (LLM) and conventional machine learning (ML) methods to predict the missing data in the early stage of development of new chemicals and materials and automate the construction of their Life Cycle Inventories.

The workflow is composed of two modules that use semantic information and molecular data relying on LLM and ML, respectively. The first module parses, structures and infers from expert knowledge provided by engineers or scientists, while the second module extracts the physical-chemical features of the new molecular configuration. Unlike existing LLM-based LCA implementations, our approach is oriented on creating inventories for innovative chemicals, and it is designed to provide fast but flexible predictions. Moreover, the workflow is meant to produce ready-to-use structured data that can be later used by any other non-AI-based tool to be analyzed or enhanced (e.g., Brightway compatible data). The results of this work are tested on two real industry case studies and can have important implications in the sustainable transition of the chemical industry.

Automated LCI Data Generation for Fine Chemicals via Retrosynthesis

Jonas Goßen, Ludwig Jolmes, Raoul Meys

Carbon Minds GmbH, Germany

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

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

approach.

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

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

From SMILES to Sustainability: Predicting the Full Life Cycle Inventory of Chemicals with Machine Learning

Shaohan Chen[1], Johannes Schilling[1], Tim Langhorst[1], Martin Pillich[1], Christopher Oberschelp[2], André Bardow[1]

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The transition toward a sustainable chemical industry underscores the importance of measuring the environmental impacts of chemical production. The environmental impacts of chemical production can be quantified across multiple impact categories using life cycle assessment (LCA). However, these LCAs require extensive life cycle inventory (LCI) data, which is often unavailable today. Current LCA databases only cover a limited number of chemicals, necessitating tedious manual work to fill data gaps for the remaining chemicals.

To fill this data gap, we propose a pathway-resolved framework to automatically predict the LCI for producing organic chemicals, enabling transparent environmental impact estimations. Specifically, from the SMILES code of a target chemical, a machine-learning-based retrosynthesis tool predicts the pathways and precursors to produce the target chemical. This retrosynthesis tool is linked to an optimization model to determine the full reaction equations, from which the feedstock demands are calculated. From the reaction equation data, we predict the remaining gate-to-gate LCI data, e.g., energy demands, by recently developed decision trees. Thereby, the framework connects the target chemical to existing LCA databases. For precursors not available in these LCA databases, their LCIA scores are predicted using a multi-task feedforward neural network. Due to the transparent modeling of pathways and inventories, the framework can be adapted for specific LCIA methods and system models and allows for refinement once better data becomes available.

We validated our framework by comparing the predicted results with a benchmark dataset of 136 organic chemicals, including industrially validated LCIs. Our method improves the accuracy and scope of predicting the environmental impacts of all impact categories. Our framework thus enables the bridging of data gaps in LCA databases for early-stage process design and accelerates the transition toward a sustainable chemical industry.

Using Large Language Models to Predict Manufacturing Processes for Mechanically Engineered Products and Fill Data Gaps in Prospective LCA

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Prospective LCA can guide sustainable product development by influencing design decisions at early stages, where flexibility for impactful changes is highest. However, its application is often constrained by limited and low-quality LCI data. For mechanically engineered products, available information is often restricted to a preliminary Bill of Materials with 3D models or technical drawings. Key information, such as manufacturing processes, is frequently unavailable at this stage. Expert estimations can address these data gaps, but they are time-consuming and limited by specialist availability. Simple algorithms, such as rule-based decision trees, provide quick estimates but struggle with complex scenarios. Additionally, addressing uncertainty is paramount for LCA, as manufacturing processes may vary depending on factors such as production location or quantity, unknown at early stages.

Machine learning (ML) methods offer an alternative for estimating LCI data automatically. However, many ML approaches rely on extensive datasets of tagged 3D models with detailed meta-information, which are resource-intensive to curate. In contrast, textual data – such as part names and manufacturing process classifications – is more accessible and easier to process.

This study explores the use of Large Language Models (LLMs) trained solely on textual product information to predict manufacturing processes, eliminating the need for large geometric datasets. The approach leverages advanced learning capabilities of ML unavailable in simple algorithms. It also emphasizes delivering predictions in an uncertainty-aware manner, laying the groundwork for future methods to quantify and reduce predictive uncertainty.

The results demonstrate that LLMs can infer manufacturing processes from textual data alone, outperforming simple rule-based methods, particularly in complex or rare cases. While LLMs do not incorporate parameters beyond textual data, such as geometric or material properties required to capture the full complexity of manufacturing processes, they show potential as a practical tool in scenarios where expert input or advanced ML models are unavailable.

Data lakes for CCF and PCF assessments – Automated approach for organizations

Sabrina Neugebauer, Desiree Lotz

iPoint systems GmbH, Germany

Against the background of increasing global climate challenges, accurately calculating the Product and Corporate Carbon Footprints of organizations has become a critical task for multi-national firms. The nature of these methods requires extensive data collection, model construction, and thus significant resources for both time and money. With this study, we approach these challenges in a threefold way: 1) use of generic models for both PCF and CCF assessments for fast forward calculation of product portfolios and various company locations, 2) definition of data fields including unique identifiers for automation through REST API, and 3) combination of primary data, classical secondary data and hybrid I/O data for mitigation of data gaps. The study is conducted in collaboration with a leading international organization of outdoor equipment / mobile living, known for its diverse product portfolio. The initial phase involved the analysis of the company's existing data repositories as well as setting up the initial generic models for PCF and CCF assessments and ensuring data/results consistency from different sources (especially LCA and I/O data). With the roll-out phase we now begin paving the way for organization wide automated assessments. One crucial step is to define all required data fields in a way that automated data flows from the organization´s

system to iPoint´s software solutions through REST API is ensured. This combined with our semi-automated mapping logic and machine learning tool in the software allows for straightforward, time optimized assessments and results that are automatically feedbacked into organization´s data systems. The study contributes a practical case study on automated carbon footprint calculations, showing ways on how organizations can efficiently calculate and therefore mitigate their overall environmental impacts.

Harnessing AI for EPD Business Intelligence: Transforming Data into Actionable Insights at Holcim

Fulei Zhou, Xavier Cieren, Nikolaos Vlasopoulos, Ines Aeply, Asfand Yar Munir, Andrea Charrier, Vasiliki Aravani

Holcim Innovation Center, France

The rapid growth of Environmental Product Declarations (EPDs) presents an opportunity to drive sustainability in the building industry. However, the volume and heterogeneity of EPD data, publicly available through entities like ECO Platform, EC3, etc., present challenges for analysis and comparison. At Holcim we are leveraging the power of Artificial Intelligence to develop an innovative EPD Business Intelligence tool, with a core focus on delivering data quality and reliability.

The tool tackles the complexities of EPD data by:

- Extracting information from raw data: Utilizing Algorithms and Large Language Models (LLMs) to efficiently extract relevant information from diverse formats like PDF, XML, and JSON.
- Curating data and estimating missing data: Employing AI algorithms to predict missing product attributes based on existing data patterns, enabling comprehensive analysis even with incomplete information and assigning confidence levels to curated data, providing users with a clear understanding of data quality and reliability.
- Detecting errors and outliers: Training Machine Learning models on existing EPD data to identify inconsistencies and anomalies, providing information to users regarding data quality.

AI has the potential to enhance data quality by enabling efficient analysis, comparison, and interpretation of EPDs. Key aspects of data quality include representativeness in terms of time (e.g., data collection year), geography (e.g., plant location, country coverage), and the reliability of EPD results (e.g., identifying outliers, detecting missing indicators, and addressing inconsistencies).

This tool provides homogeneous and comparable data that can be used to facilitate downstream EPD generation and verification efforts, improve data selection for building LCA practitioners, or enable research (e.g. what is the average installation or end of life impacts).

Presenting insights through intuitive, AI-powered chatbots and analytical tools, our web-based platform and API ensure seamless, real-time access, collaboration, and integration of high-quality, reliable EPD data, empowering users to make informed decisions.

Leveraging Semantic Technologies for Knowledge Modeling in Life Cycle Management

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[1]Luxembourg Institute of Science and Technology, Luxembourg; [2]Institute of Environmental Sciences, at Leiden University

Current approaches in Life Cycle Management(LCM) face challenges due to the complexity and volume of data. While artificial intelligence (AI) methods, particularly large language models (LLMs) offer potential, their stochastic behavior, tendency for hallucination and lack of transparency limit their applicability. Semantic technologies, by contrast, provide a structured and reproducible framework for knowledge representation and data interoperability. This study evaluates two semantic approaches - based on knowledge graphs and semantic web tools (in the form of triple stores) - to enhance data management in LCM, in particular with regard to FAIR principles and the requirement for qualified relations between entities following Linked Data standards. In the LCM context, this implies referencing agreed-upon terms—flows, processes, substances, materials, data quality, temporal validity, and their interrelations—to build consistent and interoperable datasets.

We demonstrate how semantic descriptions can enhance life cycle inventories (LCIs) using a graphene production use case. Specifically, we compare the computational demands and query-based knowledge generation capabilities required to implement the 2 approaches.

Our findings illustrate the strengths of semantic technologies in bridging the gap between data abundance and meaningful knowledge generation; how these tools show promise for applications in LCM and characterization methods; offering a transparent and interoperable foundation, semantic technologies complement AI innovations, ensuring that LCM data can be used effectively and responsibly for sustainability goals. We will be presenting key conclusions on the groundwork for future explorations into integrating semantic tools with AI methods, emphasizing explicit links and fostering interoperability across LCM systems. We highlight the potential of semantic technologies to support workflows, including AI integrations such as retrieval-augmented generation (RAG).

Development of a Smart Digital System for Carbon Management at Macau University of Science and Technology

Yahong Dong, Yu Qiu, Xiaofen Fang

Macau University of Science and Technology, Macau S.A.R. (China)

Effective carbon management has become increasingly critical for university campuses. Traditional methods for reporting and managing carbon emissions typically rely on static approaches, such as collecting data through questionnaires and manually generating greenhouse gas (GHG) reports. These methods, however, are time-consuming, lack real-time data, and hinder a comprehensive understanding of carbon emissions. Given the growing demands for rigorous GHG reporting, there is an urgent need to develop a digital system capable of integrating diverse data sources and automating data collection across various university departments.

This study presents the development of the "MUST Zero-Carbon Smart Campus System" (MUST Zero) at Macau University of Science and Technology (MUST). The system comprises nine core modules: a 3D map with information layers (showing building distribution, photovoltaic panel locations, etc.), university carbon assessment, university carbon prediction, organizational life cycle assessment (O-LCA), green building verification of MUST, real-time GHG monitoring on campus, carbon inclusiveness, and low-carbon education. The platform is further integrated with a digital twin of the campus to provide a visual representation of the university's carbon emissions.

The system accommodates five user types: system developers, university administrators, staff, students,

and guests. Data for the carbon assessment module is collected from administrators, with the previously developed carbon calculation method incorporated into the system. Starting from the 2025/26 academic year, the system will automatically calculate GHG emissions and generate GHG reports.

This presentation will detail the ongoing development of MUST Zero, providing its functionalities and modules. It will also present results from the system's carbon emissions calculations and predictions. The proposed system aims to streamline real-time carbon management, automate data collection for annual reporting, and integrate visual and real-time monitoring, enhancing the university's sustainability efforts.

Key Developments to Unlock the Full Potential of Artificial Intelligence in Life Cycle Assessment

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The planned evolution of the Corporate Sustainability Reporting Directive (CSRD) until 2028 will lead to a broader assessment of international value chains. This means that organisations of any size will soon have to generate Product Environmental Footprint (PEF) datasets. Given the current limited number of people who can carry out such assessments, it is imperative that we develop digital methods to streamline the implementation of verified Life Cycle Assessment (LCA) studies that lead to PEF datasets. In recent years, many companies have proposed to combine the information of LCA databases and data from organisations (e.g. bill of materials) by the use of Artificial Intelligence (AI) methods to automate the creation of PEF datasets. This strategy makes a lot of sense, but the data quality of PEF datasets can be questioned if we are not careful about the selection of methodologically consistent LCA datasets from available sources.

The goal of our work is first to explain the risks of current AI solutions if they use inconsistent LCA data inputs to create new PEF datasets. From there, we identify key modelling choices in the LCA method that need to be consistent between PEF datasets to ensure that AI solutions will provide trustworthy results. Finally, we propose a knowledge graph solution to streamline the integrated verification of modelling choices in AI solutions. The combination of these findings will provide the foundation to unlock the full potential of AI for LCA.

As examples of the topics that will be discussed in our presentation, we will show how different allocation choices from various LCA databases could lead to substantial mismatches in PEFs that are built from the same bill of materials. We will also highlight how location-based and market-based models for electricity can be differentiated to ensure alignment with various requirements of the assessment standards.

Session 2.14: Biogenic Carbon: Challenges of Modelling & Accounting in LCA

Time: Thursday, 11/Sept/2025: 2:30pm - 4:00pm
Session Chair: Martin Baitz, Sphera Solutions GmbH, Germany
Session Chair: Mateo Saavedra del Oso, Stora Enso, Finland

Biogenic carbon in background databases: balancing and allocation

Thomas Sonderegger, Francesco Cirone, Simone Fazio, Olivia Kaarlela, Guillaume Bourgault

ecoinvent, Switzerland

Biogenic carbon accounting is gaining momentum in LCA, particularly in key sectors for biogenic products such as agriculture and forestry. To address this, we developed a balancing approach for biomass growth processes in the ecoinvent database. It separates the “growth balance” from other flows containing biogenic carbon, such as organic fertilizers. This ensures a balance between biogenic carbon flows (in relevant products) across the system boundary and the CO2 uptake. Thereby, the carbon content of products is estimated by their macronutrient fractions. Carbon accumulated in the soil is modeled separately in land use modeling.

The growth balance makes sure that the elementary flow for CO2 uptake (“Carbon dioxide, in air”) is quantified correctly. However, in multifunctional processes this flow gets economically allocated, which can lead to distortions in the balance. We can consider a process that produces logs and wood chips 50:50, so carbon uptake goes 50:50 to these products. However, economic allocation will allocate 90:10 (assuming logs are nine times the price of wood chips) resulting in too much carbon uptake for the logs and too little for the wood chips. This distortion in the inventory results can be overcome by either applying a correction (introducing correction flows that correct after allocation) or by hybrid allocation (CO2 uptake is allocated based on carbon contents of products, losses and other elementary flows can be allocated differently).

Future conceptual developments needed are balancing carbon outside the growth balance, addressing uncertainties in agricultural and forestry datasets, and considering land use change impacts. The carbon allocation correction is already implemented in ecoinvent, a flow specific carbon allocation is not yet. The combination of a smartly designed biogenic carbon balancing in biomass growth processes and allocation rules ensures a good and consistent modeling and accounting of biogenic carbon throughout LCA databases.

Bridging Standards: Harmonising Sustainability Assessment methods for Biobased Products in Construction

Julia Weißert, Matthias Müller, Simon Panik

Universität Stuttgart, IABP, Germany

The incorporation of sustainability principles into the construction sector, particularly by promoting products of biogenic origin, has become increasingly imperative as the industry grapples with mounting pressure to mitigate its environmental impact. However, there is a paucity of unambiguous and congruent methodological approaches, with different standards and guidelines. On the one hand, the European Union (EU) has established the Product Environmental Footprint (PEF) as a unified framework for assessing the environmental performance of products. However, for applying the framework Product Environmental Footprint Category Rules (PEFCR), especially for biogenic construction products are still pending. This poses significant challenges for the assessment of e.g., timber products. Conversely, a valid Product Category Rule (PCR) for EN 15804, the standard for Environmental Product Declarations (EPDs) for construction

products, offers established environmental assessment guidelines for the construction sector. However, fundamental differences exist between the PEF and EN 15804 concerning end-of-life modelling, biogenic carbon management, and the lack of uniform data bases and requirements.

This study aims to establish a link between PEF and the EN 15804 standard, focusing on construction timber products. It provides a comprehensive guide on assessing these products according to PEF principles, leveraging the existing PCR framework. By proposing an integrated methodology, this work seeks to facilitate accurate environmental reporting and enhance transparency within the construction sector and for biogenic products. The overarching objective of this study is to cultivate a user-friendly approach to PEF application, thereby supporting the circular economy from the early design stages and concomitantly reducing the ecological footprint associated with biobased products in construction.

Returning Biogas from different feedstocks into fuels (reTURN): Carbon Footprint Modelling of Power-and-Bio-to-Liquid Fuel Tracking Biogenic Carbon

Stefanie Meilinger[1], **Felix Hoenighausen**[1], **Eva Jurgeleit**[1], **Andreas Waibel**[2]

[1]Hochschule Bonn-Rhein-Sieg, Germany; [2]Caphenia GmbH, Germany

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 BMWK, CAPHENIA GmbH is developing a technology to produce biobased synthetic fuels called Power-and-Biogas-to-Liquid (PBtL). This PBtL approach uses biogas, utilizing both biogenic methane and biogenic carbon dioxide, alongside water and electricity. The system also works with natural gas and carbon dioxide emissions from conventional power plants as well as with mixtures of biogenic and fossil feedstocks. Independent of their origin, these feedstock gases are converted in a so-called Plasma-Boudouard-Reactor (PBR) to 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 results from a prospective LCA for PBtL fuels. Our model tracks biogenic carbon (BC) throughout the entire life cycle assuming all BC originating from atmospheric CO2. We track the ratio of BC to total carbon (TC) as an additional property of all carbon containing product- and elementary flows to fairly allocate initial BC credit throughout the process chain. Impact assessment is conducted based on chemical composition of elementary flows independent of their BC content. We compare results for varying biogas feedstocks considering uptake of biogenic carbon during biomass growth and potential emissions of biogenic carbon during biogas production and other process steps.

Preliminary findings indicate a reduction in GWP100 compared to the fossil fuel benchmark outlined in the Renewable Energy Directive III (RED III), aligning with mandated GHG emission savings for biofuels.

Unraveling the Climate Neutrality of Woody Biopolymers: a Lifecycle Scenario Analysis

Akshat Sudheshwar, Kealie Vogel, Gustav Nyström, Nadia Malinverno, Monica Arnaudo, Carlos E. Gomez-Camacho, Didier Beloin-St-Pierre, Roland Hischier, Claudia Som

Empa—Swiss Federal Laboratories for Materials Science and Technology

To better understand the climate impacts of wood-based biopolymers, we conducted a comprehensive lifecycle scenario analysis for the polymers lignin and cellulose nanofibrils (CNF). We calculated the amount of carbon uptake during the "biomass cultivation" lifecycle stage of both biopolymers, compiled their various potential production impacts from literature for their "production" stage, employed static or dynamic biogenic carbon accounting for their "use" phase, and finally calculated the carbon emissions for different possible disposal routes in the "end-of-life (EoL)" stage. The carbon footprints for each option within each lifecycle stage were then added together in every possible different combination to create the scenarios used to perform a cradle-to-grave carbon footprinting assessment. This resulting extreme-value analysis differs from conventional LCA as it captures the full extent of possible impacts over different lifecycle scenarios for lignin and CNF, wherein the emissions from all possible lifecycle scenarios would likely lie within the considered lifecycle spectrum. We then benchmarked the lifecycle impacts from lignin and CNF against those calculated via the same lifecycle scenario analysis approach for several common fossil-based polymers and of one crop-based biopolymer, polylactic acid (PLA). Scenarios combining the different available production and EoL datasets in Ecoinvent for the fossil and crop polymers were created and their respective carbon footprints were plotted. The resulting carbon footprints for the wood-based biopolymers widely varied 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 CNF. In contrast, the carbon footprints for fossil and crop polymers had lower variability but no climate positivity. By calculating carbon emissions for a wide range of scenarios, we identify the potential for woody biopolymers to reduce climate impacts compared to fossil or crop-based polymers if their lifecycles involve environmentally-friendly production processes, long use phases, and well-managed EoL options.

Cradle-to-Gate Life Cycle Assessment for Advanced Biofuel Production in FLEXBY

Shravya Hebbur Murali, Sarah Serafini

GreenDelta GmbH, Germany

The FLEXBY project seeks to advance the development of cost-effective, sustainable biofuel production technologies by utilizing residual biomass, such as oily sludge from refineries and microalgae cultivated in industrial wastewater. This innovative approach integrates microwave pyrolysis to convert biomass into three valuable fractions: bio-liquid, pyro-gas, and bio-char. The bio-liquid fraction will be further processed into jet, diesel, and marine biofuels through a hydrogen-free hydrodeoxygenation method, while the gaseous fraction will be transformed into bio-hydrogen via steam-reforming and preferential CO oxidation.

A preliminary cradle-to-gate Life Cycle Assessment (LCA) is being conducted for the technology, using the latest version of openLCA, the ecoinvent cut-off database and using the Environmental Footprint LCIA method. This study focuses on assessing the environmental hotspots and a sensitivity analysis of handling multi-functionality with allocation and system expansion for the various co-products, examining their influence on overall impacts. Results from this study will be available later in the project timeline and shared. Additionally, the project will conduct a preliminary assessment of key variables, such as the impacts of microwave pyrolysis and biofuel conversion processes on resource use and emissions. It will also discuss methods to handle biogenic carbon modelling.

The first deliverable is currently due in May 2025 and results will be presented in detail at the LCM conference.

Decarbonising Construction: The role of Biogenic Carbon

Harsh Maru

Heriot watt University, Edinburgh, UK.

The construction industry, known for its diverse material usage, has garnered a negative reputation due to unsustainable practices and environmentally damaging decisions. However, research indicates significant potential for implementing sustainable Life Cycle Assessment (LCA) practices to reduce current and future emissions through biogenic carbon storage.

Current standards and methodologies for evaluating biogenic carbon in construction products lack consensus, particularly in modelling biogenic carbon. ISO 21930, for instance, does not account for land-use and land-use-change (LULUC) impacts, leading to data gaps and inconsistent decision-making. Adopting dynamic LCA within ISO 21930 could enhance the consistency of biogenic carbon results and bolster stakeholder confidence in communicating these results.

Presently, the built environment lacks clear guidelines for leveraging the benefits of biogenic carbon storage in buildings, contributing to manufacturers' greenwashing. Harmonization of Product Category Rules (PCR) is necessary to ensure comparability of results for construction products. Dynamic LCA offers promising outcomes for calculating biogenic carbon storage, incorporating factors such as timing, LULUC, and transparent data communication. However, variability in Environmental Product Declarations (EPDs) remains a significant drawback, necessitating clear guidance to prevent data miscommunication.

In summary, adopting dynamic LCA in ISO 21930 and the harmonization of PCR can lead to more accurate and reliable assessments of biogenic carbon in construction products, ultimately promoting sustainable practices within the industry.

Session 2.15: Dynamic and Prospective LCA Part I

Time: Thursday, 11/Sept/2025: 2:30pm - 4:00pm
Session Chair: Mutaz Chahrour, Mistuishi Chemical Group, Germany
Session Chair: Friedrich Jasper, Karlsruhe Institute of Technology (KIT), Germany

Combined uncertainty of static AWARE2.0 and climate models: Are climate change signals noticeable in prospective water scarcity footprints?

Georg Seitfudem[1], **Markus Berger**[2], **Anne-Marie Boulay**[1]

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Human water use exceeds safe limits, making water scarcity impact assessment crucial for Life Cycle Management. Water scarcity impact assessment with the AWARE method is sensitive to climate change – prospective studies require prospective AWARE characterization factors (CFs). But AWARE CFs are uncertain, especially due to uncertainty of the climate and hydrological models used for calculating AWARE's inputs. This work employs an ensemble approach to increase the value of static ("retrospective") and prospective AWARE for decision making, considering model uncertainty and climate change influence.

AWARE2.0 is an update to AWARE. Here, AWARE2.0 CFs are calculated for four climate change scenarios using an ensemble of five different climate models each. AWARE2.0 CFs are derived in five-year time steps until 2100. In parallel, the uncertainty of the static AWARE2.0 CFs is evaluated using a second multi-model ensemble and validations with measured river flow data, testing different uncertainty modeling approaches. Preliminary results show, first, that different uncertainty modelling approaches for static AWARE2.0 can considerably influence the final uncertainty estimations, and second, that results in arid regions are especially uncertain. Furthermore, the influence of climate data uncertainty on AWARE2.0 seems to be large, especially for the future projections. We show that for some regions matching the future scenario of prospective AWARE2.0 to the scenario of an LCA inventory might be irrelevant up to 2050. However, regional trends in future water availability are recognizable and justify the use of prospective AWARE2.0 CFs, acknowledging their uncertainty.

The uncertainty of AWARE2.0 has not been studied yet and existing future projections of AWARE do not adequately address their uncertainty. By revealing the influence of model uncertainties on AWARE2.0, the results of this study enable an in-depth interpretation of both retrospective and prospective approaches for decision-making in the context of water scarcity impacts in Life Cycle Management.

Integrated methodological framework for prospective LCA (pLCA), Social LCA (S-LCA), and Responsible Research and Innovation (RRI)

Clara Valente, **Ellen-Marie Forsberg**

Norwegian Institute for Sustainability Research (NORSUS)

Traditionally, Life Cycle Assessment (LCA) has been applied to evaluate mature technologies. Recently, the role of Anticipatory LCA or Prospective LCA (pLCA) has been a topic of growing interest (Arvidsson et al. 2024).

While pLCA is primarily used to assess the environmental implications of emerging technologies, its use could be extended to evaluating broader societal implications. Conducting prospective social LCAs is in line with a holistic view on sustainability and such methodological innovations are already seen in the literature. In view of the data challenges faced in situations of anticipatory social LCA, qualitative assessments involving stakeholders are often recommended (see e.g. Nubi et al. 2021). When engaging in anticipatory

assessment the approach of Responsible Research and Innovation (RRI) appear particularly relevant. RRI can play a complementary role to pLCA by identifying future challenges, anticipating potential problems, exploring alternatives, and reflecting on underlying societal values (Thorstensen and Forsberg 2016).

This paper introduces an integrated methodological framework combining pLCA, S-LCA, and RRI, applied to three case studies:

1. Fish Feed Production: the conversion of low-value by-products from sawmills into high-value bioproducts by producing single-cell protein through the integration of pyrolysis, syngas conditioning, and fermentation processes
2. Smart Greenhouse Cultivation: tomato cultivation in smart greenhouse systems, where an innovative Environmental Control System is implemented to enhance yield and quality.
3. Smart Sensing for Protein Analysis: a smart sensing platform designed for protein and peptide analysis, enabling the evaluation of protein quality in protein hydrolysates.

References:

Arvidsson et al. 2024 Terminology for future-oriented life cycle assessment: review and recommendations | The International Journal of Life Cycle Assessment

Nubi et al. 2021: A Prospective Social Life Cycle Assessment (sLCA) of Electricity Generation from Municipal Solid Waste in Nigeria

Thorstensen and Forsberg 2016: Social Life Cycle Assessment as a resource for Responsible Research and Innovation

Dynamic environmental impact analysis of a hydrogen refuelling station's operation

Domen Hojkar, Boštjan Drobnič, Mitja Mori

University of Ljubljana, Faculty of Mechanical Engineering, Slovenia

For hydrogen to contribute to the decarbonization of mobility, its environmental impacts must be minimized. A comprehensive life cycle assessment (LCA) is essential to evaluate the environmental impacts across the hydrogen value chain, including production, conditioning, distribution, and end-use. While studies show that renewable hydrogen can meet the stringent EU emissions thresholds when the entire value chain is connected to renewable electricity sources, they often omit detailed consideration of the intermittency of those sources and the impact this has on the actual emissions. Applying temporal resolution to LCA modelling enables a better understanding of environmental impacts associated with intensive electricity use in the hydrogen value chain.

While hydrogen refueling stations (HRS) are not the largest electricity consumers in the hydrogen value chain, their operations can lead to significant emissions when electricity demand coincides with periods of low renewable energy generation in the grid. This is unavoidable when the primary focus of the HRS is to maintain consistent operations and accommodate as many customers as possible. With an increasing share of intermittent renewable energy sources in the national power grids, there is a strong need to account for temporal variations in the environmental impact of electricity use and to model environmental impacts dynamically.

This study develops a dynamic model of HRS operations, incorporating realistic operation patterns of compressors, chillers, and other key components. A temporal electricity mix model is constructed with an hourly resolution, enabling a comparative analysis of environmental impacts using annual average emission factors versus hourly electricity matching. Optimization models are implemented to shift electricity demand to periods of lower grid emissions, minimizing environmental impacts without disrupting HRS's operations.

This study demonstrates the importance of integrating temporal resolution into LCA modelling for electricity-intensive systems. Additionally, the temporal resolution unlocks opportunities for system optimization

that static LCA approaches cannot provide.

A Novel Low-Energy Approach To Lithium-Ion Battery Recycling And The Recovery Of Secondary Aluminium

Federico Rossi[1,2], Monia Niero[1,2], Filippo Corsini[1,2], Marta Fundoni[2], Nicola Fabbri[2], Fabio Iraldo[2,1], Marco Frey[1,2]

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Recovering valuable materials from waste batteries offers a great opportunity to address circular economy goals and mitigate supply risks associated with rare earth elements. However, current battery recycling methods often entail significant environmental impacts due to the energy-intensive nature of pyrometallurgical processes and the extensive use of inorganic acids in hydrometallurgical treatments.

This study evaluates the environmental performance of an innovative lithium-ion battery recycling technology developed within the Tech4Lib project, funded by Fondazione Cariplo. The recycling process begins with "black mass," a blend of metals derived from the pre-treatment of waste cells through disassembly and shredding. The black mass is processed using a microwave-assisted carbothermic reaction, which significantly reduces energy consumption compared to traditional pyrometallurgical methods. Following this, rare earth elements are recovered via leaching, achieving a recovery rate exceeding 95% for lithium and cobalt. Unlike conventional hydrometallurgical processes, the Tech4Lib technology employs malic acid—sourced from food waste—as a secondary, sustainable leaching agent. In addition, we also consider the recycling of the aluminium content of the battery system (which is often used as current collector of electrochemical cells). Since aluminium is not recovered in the Tech4Lib, its recycling has been modelled using primary data collected in the context of the GRINS "Growing Resilient, INclusive and Sustainable", project founded by the European Union - NextGenerationEU program..

The Tech4Lib process demonstrates promising potential for battery recycling by leveraging secondary resources and low-energy sub-processes. However, as an emerging technology at the laboratory scale, its energy and material efficiencies remain unoptimized. To address this, prospective Life Cycle Assessment (LCA) was conducted to analyze future scenarios reflecting the anticipated industrial-scale application of the process. The findings reveal significant potential for environmental performance improvements, suggesting that the Tech4Lib process could become competitive with existing recycling technologies.

EXIOFUTURE in a Circular Economy Framework

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EXIOBASE is a global multi-regional input-output (MRIO) model analyzing the flow of materials, energy, and emissions across sectors and regions. It assesses the environmental impacts of global supply chains, focusing on resource use and greenhouse gas emissions. EXIOBASE identifies key environmental pressures and supports sustainability assessments on a global scale.

EXIOFUTURE extends this framework into a scenario-based model to explore future material and carbon impacts under different socio-economic conditions. By linking Integrated Assessment Models (IAMs) with NTNU's MRIO framework, EXIOFUTURE simulates the transition to a sustainable, low-carbon economy. It evaluates the long-term effects of policy and technological changes in the context of a circular economy and climate change mitigation.

This framework is supported by two key projects: CircoMod (Circular Economy Modelling for Climate Change Mitigation) and CircEUlar (Developing Circular Pathways for an EU Low-Carbon Transition). These

projects integrate circular economy strategies into MRIO models, identifying pathways to reduce material consumption and emissions while supporting economic and technological development.

The framework focuses on two critical sectors: buildings and machinery.

In the building sector, high material and energy demands, combined with long lifespans, present challenges. This framework analyzes material and carbon dynamics, exploring reuse, refurbishment, and material efficiency. It evaluates how policies and technologies can reduce emissions and material consumption in construction, aligning with EU climate-neutral goals.

In the machinery sector, rising demand for automation, renewable energy technologies, and industrial robotics drives material and carbon impacts. Scenario-based modeling examines global metal demand, emissions, and production systems, particularly in developing regions and sustainable energy solutions. Circular economy strategies, such as recycling and material efficiency, are analyzed to mitigate environmental impacts. EXIOFUTURE offers essential tools for advancing circular economy practices and achieving global sustainability goals.

Responsive scenario building for pLCA & dMFA - An integrated approach

Sjoerd Daniël Matthijs Herlaar, Martijn Kamps, Chen Li, Anna Schwarz

TNO, The Netherlands

Successful decision-making for sustainability requires a systemic perspective that reveals the interconnections between environmental and economic systems. Integration of Dynamic Material Flow Analysis (dMFA) and Prospective Lifecycle Assessment (pLCA) can provide such a systemic perspective by bridging macro-level (economy-wide) and micro-level (product-specific) analyses.

To enable this integration, we developed a novel methodology for large-scale, precise adjustments to LCA databases. The method employs configurable algorithms to simulate various intervention types, focusing on both foreground (product-level) and background (system-level) aspects of LCA models. Written in Python and compatible with the Brightway ecosystem, including PREMISE, the method automates database modifications by manipulating raw matrices (A and B matrices) exported from the LCA database. These modified databases can subsequently be used for the pLCA and the dMFA.

Foreground interventions, such as material substitutions or process efficiency improvements, are modeled by altering the technology matrix, while background interventions, such as policy-driven changes in energy mixes or recycling quotas, are captured by modifying a set of background processes. This modular approach supports the systematic application of diverse scenarios, enabling scalable and flexible LCA studies. A user-friendly, Excel-based GUI lowers barriers to creating custom scenarios.

The framework's integration with dMFA allows resource flow results to dynamically update LCA databases over time, while LCA results influence dMFA. This bidirectional interaction enables systemic assessments of the cascading effects of interventions on resource use and environmental impacts. Additionally, the methodology can operate standalone for scenario design in pLCA.

The framework is demonstrated through a case study on photovoltaic (PV) panels in energy systems. Using Brightway, LCAs for different PV panel types are dynamically adjusted over time under various scenarios, showcasing the flexibility and capabilities of the methodology. The case study highlights the capabilities of the methodology and the importance of systemic modelling.

Considering Uncertainty in the Socioeconomic Impact Analysis of Plant Resource Utilization Technologies: Methods of Material Flow Analysis and Input-Output Analysis

Shunichi Hienuki[1], Yuko Oshita[2], Daisuke Nishijima[3], Yuichiro Kanematsu[2], Yasunori Kikuchi[2]

[1]Central Research Institute of Electric Power Industry; [2]The University of Tokyo; [3]Fukushima University

Japan remains heavily dependent on imported fossil resources, not only for power generation and transportation but also for the production of chemical products. To reduce this reliance, the country has been actively investing in the development of technologies that transition from fossil-based to plant-based resources. Evaluating these technologies requires a comprehensive approach that considers not only greenhouse gas emissions and resource consumption but also their broader socioeconomic impacts.

This study developed a practical model that combines Material Flow Analysis (MFA) with Input-Output Analysis (IOA), creating a framework capable of addressing both technological and societal uncertainties. The MFA component provided a detailed breakdown of material flows across the entire lifecycle of cellulose nanofiber (CNF)—a plant-based material celebrated for its high strength, lightweight characteristics, and biodegradability. The analysis included scenario development to explore critical factors such as production efficiency, recycling rates, and market adoption. These scenarios helped reveal how variations in these parameters influence CNF's overall material flow dynamics. Sensitivity analyses added further depth by quantifying the impacts of these variations.

The IOA component extended this analysis by integrating the material flow scenarios into an economic framework. This allowed for the evaluation of CNF's direct and indirect socioeconomic effects across various industrial sectors. The results highlighted its influence on value-added contributions, cost structures, self-sufficiency rates, and the interconnectedness of different industries. Detailed sensitivity analyses further examined how market fluctuations, technological advances, and policy shifts could shape these economic outcomes.

By addressing uncertainties in both technological and societal contexts, this study introduced a novel and holistic approach to evaluating plant-based resource technologies. The integration of MFA and IOA offers valuable insights for policymakers and industry leaders, shedding light on the potential of sustainable materials like CNF to support Japan's transition toward a circular economy.

Life Cycle Assessment of prospective French electricity scenarios in 2050

Joanna SCHLESINGER-MARTINAT[1], Romain SACCHI[2], Juliana STEINBACH[1], Paula PEREZ-LOPEZ[1], Thomas BEAUSSIER[1]

[1]Mines Paris, Université Paris Sciences et Lettres, France; [2]Paul Scherrer Institute, Suisse

Context

The energy sector, which accounts for 34% of human-caused greenhouse gas emissions [IPCC 2023] is expected to change significantly within the next 30 years. In France, the evolution of the electricity sector is mainly driven by the upcoming closure of most nuclear plants, which currently provide around two-thirds of French electricity. The composition of France's future electricity mix is yet to be defined, and several prospective studies have been carried out in recent years to explore potential outcomes.

Objectives

This study aims to develop a comprehensive prospective Life Cycle Assessment (LCA) framework to assess the potential environmental impacts of future French electricity mixes. We aim to compare different French prospective scenarios against their lifecycle-based environmental impacts.

Methodology

The prospective LCA methodology integrates national energy scenarios – provided by the French Transmis-

sion System Operator (RTE) - into the ecoinvent database. These French scenarios include varying reliance on renewable energy and new nuclear facilities. To account for prospective evolution of background data, global energy scenarios are also incorporated. The modeling uses the Python libraries premise, brightway and lca_algebraic.

Outputs

Concerning the development of the prospective LCA framework, the high variability of the results leads us to explore the influence of some methodological choices, such as global energy scenario selection or production versus consumption-based electricity mix.

Several consumption and production scenarios are compared by 2050. Considering the climate change impacts of 1 kWh of French consumption-based electricity in 2050, the two main conclusions are that:

- the impacts per kWh for renewable scenarios are always higher by 30 to 35% than for nuclear scenarios;
- the French electricity mix cannot be low-carbon if the European mix is not strongly decarbonized due to electricity imports.

This study helps to better evaluate the potential impacts of different national electricity strategies and can contribute to guiding these strategies.

Challenges for Prospective Life Cycle Assessment of Information and Communication Technology

Anna Furberg[1,2,3]

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The ongoing and rapid digital transformation of society, exemplified by significant investments being made in artificial intelligence (AI) and data centers, have led to concerns for increased future emissions from the digital sector. To inform decision-makers on different trajectories for information and communication technology (ICT), it is important to apply a life cycle perspective and conduct prospective life cycle assessment (PLCA) of ICT. While assessments of the future are inherently challenging, PLCA of ICT is especially challenging due to the sector's rapid development and so far, studies conducting PLCA of ICT have been limited. The aim of this study is to identify and highlight critical challenges for PLCA of ICT. This includes to discuss how these challenges can be addressed in assessments and to identify needs for future research. Based on a literature review and the expertise of the author, several critical challenges for PLCA of ICT were identified, including but not limited to: i) high model complexity due to rapid technology development, ii) interdependence between products and services (e.g., AI) and their infrastructure (networks and data centers) as well as between hardware and software and iii) indirect effects of ICT that could lead to both increased and reduced impacts in other sectors. These challenges, in combination with the selected study goal and scope, affect how LCA practitioners need to deal with the future, select time horizons to be studied and address uncertainty in assessments. There is a need for more case studies applying PLCA of ICT and some initial suggestions are made on lines of inquiry. Importantly, challenges for PLCA of ICT need to be acknowledged in assessments to ensure the provision of documentation for decision-making towards reduced environmental impacts of ICT.

Session 2.16: Using LCSA for Industry Decision-Making Part I

Time: Thursday, 11/Sept/2025: 2:30pm - 4:00pm
Session Chair: Nils Jäger, thyssenkrupp Steel Europe AG, Germany
Session Chair: Julian Suer, thyssenkrupp Steel Europe AG, Germany

Mapping the uncertain risks and impacts of substances of concern in product lifecycles – a circular design tool for product developers

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Substances of concern (SoC) are harmful to human health and the environment upon exposure, generating potentially cumulative risks throughout the initial and subsequent lifecycles (i.e., reuse and recycling) of the products that contain them. Current approaches towards SoC focus on developing safer chemicals; however, this is often not feasible, or safety data is insufficient or unavailable [1], requiring product developers to employ alternative strategies, i.e., reduce or control [2].

The design of a product, in combination with its context, determines lifecycle impacts and risks, which product developers substantially influence. This requires risk and impact assessment to inform decision-making, especially during early-stage development phases with high uncertainty. However, methods like Life Cycle Assessment (LCA) and Risk Assessment (RA) require detailed data, typically unavailable during early development stages [3]. Thus, tools to assess SoC risks during early design phases are lacking. To address this, we developed a tool to identify SoC risks and environmental hotspots across a product's lifecycle, accounting for uncertainties and trade-offs.

We developed this tool by analyzing historical cases of products modified to mitigate SoC risks, such as mattresses containing flame-retardants and plasticized PVC cables. Additionally, we collaborated with product developers, LCA, and RA experts to verify our insights and ensure the tool's usability in real-world applications.

The tool provides an iterative, intuitive framework for assessing SoC risks and trade-offs during early development. It visualizes SoC risks and environmental impacts across lifecycles, adapting and integrating RA (hazard identification, exposure assessment) and LCA elements (system mapping, functional unit). It uses bills of materials, LCA databases, and available chemical data as inputs [4]. Product developers can assess existing products, compare design alternatives, map uncertainties, highlight data gaps, and navigate environmental, safety, and performance trade-offs. Complex information is simplified into visuals, improving communication among product developers and stakeholders, while supporting informed decision-making.

Leveraging Circularity to Mitigate GHG Emissions: Measurement Options and Incentive Mechanisms

Christian Krüger[1], Florian Ansgar Jaeger[2], Johannes Wunderlich[2]

[1]BASF, Germany; [2]Siemens, Germany

Circularity plays a crucial role in the transition to a net-zero economy, as it enables the recycling of waste materials, thereby reducing the energy-intensive production of virgin materials and minimizing CO2 emissions at end-of-life. This shift typically results in lower greenhouse gas emissions. However, the current level of circularity within the chemical industry remains alarmingly low, primarily due to the associated cost increases. For instance, global plastic recycling rates are below 10%, with Europe leading at just 19%.

Industry and policy targets are essential in catalyzing efforts across the supply chain to enhance circularity. Increasingly, organizations are incorporating greenhouse gas emissions reduction into their purchasing decisions, making carbon accounting methodologies critical for business operations. To facilitate effective supply chain decisions based on sustainability KPIs, there is a pressing need for comprehensive data availability and standardized metrics.

Efficient integration of fully digitalized tools within organizations and across supply chains is vital for achieving these goals. Some sectors are leading the way, exemplified by initiatives like “Together for Sustainability” in the chemical industry and “catena-X” in the automotive sector. Both initiatives advocate for a harmonized Product Carbon Footprint (PCF) standard, ensuring transparency and consistency in chosen methodologies.

This presentation will delve into selected aspects of PCF methodology from the discussions within Together for Sustainability and catena-X, focusing on biogenic and recycled materials. We will explore the implications of these methodologies on real-world product examples and discuss the most effective incentives for supply chain stakeholders to enhance both circularity and greenhouse gas emissions reduction.

Sustainability reporting and compliance within the EU: opportunities and challenges of LCA assessments in the copper, nickel, zinc and precious metals industry

Lígia da Silva Lima[1], Patrick Van Sprang[1], Sabina Grund[2], Hemant Sharma[2], Mark Mistry[3], Pablo Dominguez[3], Ladji Tikana[4], France Capon[5], Maxime Lambert[5]

[1]ARCHE Consulting; [2]International Zinc Association; [3]Nickel Institute; [4]International Copper Association; [5]European Precious Metals Federation (EPMF)

The EU has prioritized the decarbonization of the transport sector and energy mix to achieve climate neutrality by 2050, with substantial investments in green technologies like batteries, solar panels, and wind turbines. Advancements in these technologies, often supported by automation and artificial intelligence, also raise the need for digital devices (powerful computers, servers, data transmission network). These technologies rely on metals, driving a surge in demand. To ensure sustainable metal and technology supply, the EU has introduced regulations emphasizing environmental standards and requiring life cycle assessment (LCA) for environmental performance evaluations. Key policies include the Batteries Regulation, Ecodesign for Sustainable Products Regulation (ESPR), the Critical Raw Materials Act (CRMA), Carbon Border Adjustment Mechanism Regulation (CBAM), and the Product Environmental Footprint (PEF) Programme. The Safe and Sustainable by Design (SSbD) will also play an important role, especially in the use of LCA for novel technologies.

Clearly, policy development has been driving LCA development and vice versa. LCA methodologies are central to compliance, but while some documents like the PEF Guideline and Batteries Regulation offer clear guidance on functional units, system boundaries, and databases, others do not address all these aspects. Carbon footprint dominates the focus, while other critical environmental impact categories are under scru-

tiny. This study reviewed 21 documents, including regulations, recommendations, standards and directives to evaluate LCA requirements for metals such as Cu, Ni, Zn, Au, Ag, and platinum group metals, highlighting gaps in consistency and comprehensiveness in LCA guidance.

Providing a Science-Based and Harmonized Environmental Scoring Scheme for Cosmetics: The EcoBeautyScore

Laurent Gilbert[1,3], Sophie Achigar[1,2], Alessio Aufoujal[1,2], Tasnim Balgobin[1,2], Eric Bone[1,3], Andrea Carrao[1,4], Iguatemi, M. Costa[1,5], Stéphanie Johann[1,2], Mathilde Kolenda[1,2], Sacha Laruelle[1,6], Rebekah Lees[1,2], Jacques L'Haridon[1,3], Camille Martin[1,3], Olena Onyshchenko[1,7], Anke Pilzner[1,8], Jennifer Saxe[1,9], Pascal Seel[1,8], Harald Streicher[1,8], Laura Tasso[1,2], Jad Zoghaib[1,3]

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The EcoBeautyScore (EBS) Association, having gathered since its inception in 2021 over 70 global cosmetic companies and professional associations, has developed a unified environmental footprint measurement and scoring system for cosmetic products. This system is based on Life Cycle Assessment and builds on the Product Environmental Footprint (PEF) guideline initiated by the European commission in 2013. Moreover, the method was enhanced to suit the specificities of cosmetics. This communication is dedicated to presenting the overall EBS footprint and scoring methodology.

The EBS footprint methodology aligns with the key PEF principles, assessing 16 midpoint impact categories across a full cosmetic product's lifecycle. Products are evaluated based on their functional unit, using a data hierarchy to derive usage doses for cosmetic technologies. Moreover, to address limitations concerning robustness and data coverage in the PEF-prescribed USEtox 2.1 model for freshwater ecotoxicity, an adapted method was implemented using the Most Sensitive Species-HC5 (hazardous concentration for 5% of species) approach.

A common database for production and end-of-life impacts of standard ingredients was created, prioritizing prevalent and impactful ones, complemented by a comprehensive data strategy. Significant enhancements in data coverage and quality for the end-of-life ecotoxicity freshwater database were achieved by developing new characterization factors. Furthermore, incorrect and obsolete factors were replaced to enhance applicability of USEtox for cosmetics.

To make PEF outcomes clear to consumers, a product segmentation approach is used, comparing only products with the same primary cosmetic benefit. A portfolio assessment combined with a representative sampling defines environmental performance classes from A to E per segment.

Tested on over 2,700 products, results show that for rinsed-off products like Hair Wash, the use phase is a major PEF contributor, followed by ingredient production and end-of-life. For Face Care products, ingredients are also a significant contributor and packaging production has a more significant impact.

Integrating Life Cycle Sustainability Assessment (LCSA) for Sustainable Waste Management in Humanitarian Operations: Insights from the Bio4HUMAN Project

Carolina Szablewski[1], Perrine Sebastien[1], Emilie Guilvert[1], Carla Bartolomé[2], Andrea Rodenas[2], Clara Casado[3], Marta Rumayor[3]

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Humanitarian operations generate thousands of tons of solid waste annually, much of which is non-biodegradable, contributing to environmental degradation and public health risks. To address this challenge, the Bio4HUMAN project promotes sustainable waste management through bio-based solutions and life cycle thinking. The project aims to reduce the environmental footprint of humanitarian aid by integrating innovative practices, such as the use of biodegradable packaging and efficient waste management systems in refugee camps.

The project targets two case studies in South Sudan and the Democratic Republic of Congo, analyzing the feasibility of implementing bio-based solutions under local conditions. By identifying gaps in the supply chain and assessing sustainable waste reduction options, Bio4HUMAN seeks to advance practical and scalable solutions tailored to humanitarian contexts.

At the heart of the project is a Life Cycle Sustainability Assessment (LCSA) approach, which evaluates bio-based solutions across environmental, economic, and social dimensions. Different kits for food and non-food items, designed for one family, were defined in collaboration with partner NGOs in the Bio4HUMAN consortium. These kits are analyzed through multiple value chains based on the sourcing of their components—international, national, or local. The project compares the sustainability of bio-based materials with existing solutions, examining critical factors such as the origin of raw materials, processing methods, and transportation distances. This cradle-to-grave evaluation ensures that all stages of a product's life cycle are considered, providing a comprehensive sustainability analysis.

The project outcomes will include a roadmap for replicating successful waste management practices in other humanitarian contexts. By integrating LCSA into decision-making, Bio4HUMAN enhances the sustainability and effectiveness of humanitarian interventions, fostering resilient ecosystems and healthier communities.

Funded by the EU Horizon Europe Research and Innovation Program, Grant Agreement 101135144.

Environmental and operational optimization of Central Sterile Supply Departments in hospitals

Robin Schlembach[1], Lukas Messmann[1], Sebastian Schiffels[1], Axel Tuma[1], Jens O. Brunner[2]

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Central Sterile Supply Departments (CSSD) play a critical role in the operation of hospitals and for their overall environmental footprint. Operationally, the batching of jobs and their scheduling and allocation to washer-disinfectors and sterilizers is a complex decision-making problem, with CSSDs being potential bottlenecks in surgery scheduling. Environmentally, on the one hand, CSSDs enable the reusing of surgical and other sterile equipment and thus help to reduce the environmental impacts of production and waste treatment associated with alternative disposable solutions. On the other hand, CSSDs themselves consume substantial amounts of electric and thermal energy, chemical cleaning agents, water, and disposable equipment (e.g., face masks, gloves, fleeces). Critically, operational goals (e.g., completion times or makespan) and (various) environmental objectives are often strongly conflicting. In this work, we develop a two-stage batch-scheduling flexible flow shop optimization model of a CSSD, which is parameterized with real-world, Life Cycle Assessment-based environmental data. We resolve conflicts between objectives (e.g., completion times vs. environmental impacts) by multi-criteria optimization and present theoretical Pareto-optimal

compromise solutions as well as practical hints for improving both the operational efficiency and the sustainability of hospitals.

Session 2.17: LCA & LCM for Improved Energy Decision-Making Part II

Time: Thursday, 11/Sept/2025: 2:30pm - 4:00pm
Session Chair: Luka Smajila, KTH - Royal Institute of Technology, Sweden
Session Chair: Ketan Vaidya, ex-Northvolt AB, Sweden

Life-cycle assessment of thermal energy storage in buildings

Haoyang Dong, Maryna Henrysson, Luka Smajila, Saman Nimali Gunasekara, Justin Ningwei Chiu

KTH Royal Institute of Technology, Sweden

Thermal energy storage (TES) plays an important role in enhancing energy efficiency and flexibility in building systems. This study develops a method for conducting life-cycle assessment (LCA) studies for evaluating the environmental performance of TES in different configurations. A case study is carried out, comparing phase change material (PCM)-TES, water-TES, and borehole-TES. Cradle-to-grave life cycle inventory is analyzed over a 25-year lifetime, and ReCiPe 2016 midpoint (H) is used for midpoint impact categories quantification. Results show that TES integrations yield the lowest life cycle impact in Global warming potential, surplus ore potential, marine eutrophication and water consumption amongst others against non-TES reference during operational phase. It is also shown that the predominant GWP impact of TES integration comes from production, installation, and end-of-life phases.

Who will benefit from second-life batteries? Life Cycle Assessment of Battery Energy Storage Systems

Julia Lindholm[1], Zackarias Heydorn[1], Gustav Dahlberg[1], Elham Moghaddam[1], Niklas Thulin[2], Siri Willskytt[2]

[1]IVL Swedish Environmental Research Institute; [2]Volvo Energy

As the electrification of the mobility sector accelerates, the number of batteries reaching end-of-life will also increase significantly in the coming decade. While not always suitable for reuse in another vehicle, these batteries present an opportunity for reuse in Battery Energy Storage Systems (BESS), extending their useful life and reducing the need for newly produced batteries. Reuse is also a more favourable option than recycling according to the waste hierarchy.

This study aims to evaluate the environmental trade-offs of using second-life batteries in BESS versus using newly manufactured batteries. This study uses life cycle assessment (LCA) to assess the climate change implications of BESS configurations using second-life Nickel Manganese Cobalt (NMC) batteries from Volvo commercial vehicles and new Lithium Iron Phosphate (LFP) batteries under two operational scenarios: low-energy throughput and high-energy throughput. The use phase is modelled in Sweden and Poland, considering varying grid conditions. Additionally, three EoL modelling approaches—simple cut-off, cut-off with credits, and avoided burden—were applied to evaluate the influence of methodology and its alignment with industry practices.

The results show that second-life NMC batteries have a lower climate impact than new LFP batteries in all studied scenarios except in high-energy use cases with carbon-intensive electricity mixes, where the lower round-trip efficiency of the second-life batteries affects the outcomes significantly. These results emphasize the importance of tailoring BESS configurations to energy demands and grid conditions. Furthermore, the choice of EoL modelling approach significantly influences these outcomes, shifting the benefits of reuse between the second-life user and the battery supplier. This study provides critical insights for advancing sustainable resource management and guiding stakeholders in optimizing battery reuse strategies in align-

ment with circular economy principle.

Multi-criteria assessment of hydrogen delivery options: including accident impacts into LCA

Alessandro Arrigoni, Erik Smedberg

JRC, The Netherlands

As the European Union prepares to import large quantities of low-carbon hydrogen, the optimal form of delivery remains uncertain. Previous techno-economic and life cycle assessments by the Joint Research Centre of the European Commission compared the costs and environmental sustainability of various delivery options, including gaseous hydrogen, liquid hydrogen, and chemical carriers such as ammonia, methanol, synthetic natural gas, and liquid organic hydrogen carriers. Renewable liquid hydrogen transported by ship and compressed hydrogen transported by pipeline proved to be the most economically and environmentally sustainable options to deliver hydrogen for the 2500-km distance considered in the assessment. Packing hydrogen into more manageable carriers results in a transport efficiency advantage, but it does not seem to result in an environmental impact advantage. However, the study assumed a zero-risk scenario, neglecting the potential environmental impacts of accidents during delivery. This research addresses this limitation by estimating accident risks and incorporating their environmental consequences into the multi-criteria assessment. It is highlighted that excluding accidents from the environmental profile of hydrogen carriers provides an incomplete picture of their sustainability. We argue that a more systematic approach to integrating risk assessments into comparative LCAs is essential for informed decision-making in the transition to a low-carbon hydrogen economy.

Comparative analysis of energy storage technologies to compare batteries, hydrogen storage, and thermal energy storage through energy flow simulations

Ayumi Yamaki, Shoma Fujii, Yuichiro Kanematsu, Yasunori Kikuchi

The University of Tokyo, Japan

Power generation derived from variable renewable energy (VRE) has been accelerated toward achieving carbon neutrality. However, it is challenging to ensure a stable power supply with VRE-derived energy because of its intermittent characteristics. To supply power on demand, installing energy storage systems that connect VRE is essential. We aim to evaluate the environmental impacts of an energy storage system to select the appropriate storage system. This study targeted batteries, hydrogen storage, and thermal energy storage as energy storage technology: wind as VRE. To compare the energy storage systems for connecting large-scale VRE to the grid, a model of the energy storage system with VRE was constructed, and the annual energy flow was simulated. The energy storage system of this study assumed that all the energy derived from VRE was stored in the energy storage technology and supplied electricity to consumers. The energy flow was calculated hourly from 0:00 on January 1st to 24:00 on December 31st. A life cycle assessment was conducted to evaluate the greenhouse gas (GHG) emissions and abiotic resource depletion (ARD) through LIME2, which is constructed by considering Japanese environmental conditions, and Product Environmental Footprint (PEF), which is proposed by the European Commission as a common way of measuring environmental performance, to compare their evaluation results. The amount of power to be sold from the energy storage system under different penetrations of the VRE and energy storage technologies was calculated. The smallest GHG emissions and ARD varied depending on the type and amount of energy storage. A quantitative evaluation of the energy storage system, such as the energy supply capacity and the environmental impacts, could assist in designing an energy storage system with VRE, considering regional energy supply systems.

Bringing wind energy models up to speed: Updated life cycle inventory data for on- and offshore wind energy generation

Hanna Kröhnert, Alena Frehner, Matthias Stucki

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Wind energy plays an increasing role in the electricity mixes worldwide. In Europe, the installed wind power capacity doubled from 135 GW to 270 GW in the last decade, reaching an electricity market share of 13% in 2023. This trend is expected to continue, with projections of 500 GW installed wind power capacity by 2030.

Along with new wind farm projects, the technology of wind turbines developed rapidly. The average nominal power capacity of installed onshore wind turbines in Europe increased from 2.5 MW to 4.5 MW in the last decade. The average nominal power capacity of offshore wind turbines increased from 3.8 MW to 9.7 MW. Projected offshore parks consider turbines of 15 MW and higher.

Despite these advancements, environmental assessments of wind energy still largely rely on outdated inventory data, with corresponding background databases dating back to the early 2000s. These models cover only wind turbines with nominal capacities of up to 2 MW and no longer reflect current technologies. The life cycle inventories for wind energy therefore urgently need to be updated.

This study provides the needed update for wind energy for the Swiss Life Cycle Inventories database, focusing on the European context. The results of the study were also incorporated into the new IEA Wind Task 60 CYCLEWIND for harmonizing LCA of wind energy. The updated inventories cover current technologies and nominal power capacities of wind turbines from 2 MW to 15 MW. Furthermore, inventories for electricity from wind energy were updated, considering representative European wind farms and capacity factors. With resulting greenhouse gas emissions between 10.4 and 22.7 g CO2-eq/kWh, wind energy remains among the power generation technologies with the lowest climate impact.

At the LCM 2025, the updated inventory data and resulting environmental impacts, including climate impact and Environmental Footprint, are presented and discussed.

Power-to-X or storage of CO2 after capture from a waste-to-energy system?

Ingunn Saur Modahl, Hanne Lerche Raadal

NORSUS - Norwegian Institute for Sustainability Research, Norway

Carbon capture and storage (CCS), or utilization (CCU), is increasingly focused as important solutions for climate mitigation. While CCS stores the carbon dioxide permanently, CCU transforms the carbon in the captured CO2 into fuels or other products. For this, large amounts of energy are required, hence 'Power-to-X'.

Life Cycle Assessment (LCA) is often used to compare products. This is challenging for CCU products, as CCU systems are multifunctional. As a result, LCAs of CCS and CCU systems are often prone to methodological pitfalls. In their ultimate consequence, such pitfalls can affect political decisions. Hence, this study has been carried out using the LCA guidelines provided by Müller, Kätelhön et al. (2020) and von der Assen, Jung et al. (2013).

In the LOUISE project, the aim was to prepare for pre-commercial demonstration of Chemical Looping Combustion (CLC) of solid waste-derived fuels. In this process, a metal oxide acts as an oxygen carrier. Combustion with this oxygen produces a flue gas highly concentrated in CO2, enabling efficient CO2 sepa-

ration.

In this presentation, LCA results will be shown for two CCS cases and two CCU cases. As CCU products, both methanol and acetic acid are investigated. Comparisons with a reference system using amine post-combustion capture and a reference without capture will be presented.

The results show that CLC performs well in comparison with other capture technologies in terms of climate change. For all other indicators than climate, the environmental burdens increase for CCS systems relative to a reference scenario without capture. CCU for fuels and chemicals is found unfavourable if fossil electricity can be replaced in the grid (which is not specific for CLC but for CCU in general). Scenarios will be used to show under which circumstances CCU fuels still can be beneficial with regard to climate effects.

How should lifecycle design and technological research be integrated? ; Case study on thermal energy storage

Shoma Fujii, Yasunori Kikuchi

The University of Tokyo, Japan

Sustainability certification / standardization is becoming a business even without enough academic validation such as life cycle management (LCM), and there is a gap between life cycle management (LCM) and certification. Furthermore, LCM does not always adequately reflect data from technology development, and there is a gap between LCM and technology development as well. In order to seamlessly connect the technical development of emerging technologies, LCM including their evaluation and design, and the certification/standardization of sustainability, it is important to organize the granularity and accuracy of emerging technology development data when connecting each activity. The authors are conducting research, development and LCM on various scales (lab, bench and pilot scale) on emerging technology of thermal energy storage for decarbonization of heat, which accounts for half of final energy consumption in the world. Using thermal energy storage technology as a case study, the question of what granularity and accuracy of data should connect LCM with the development of emerging technologies was examined. Thermal energy storage is a technology to circulate and utilize unused heat in a region by charging unused heat derived from waste incineration, storing it in a thermal energy storage material, transporting the thermal energy storage material to demands, and discharging the stored heat at the location where heat supply equipment such as boilers are installed. The feasibility of this thermal energy storage was experimentally and numerically evaluated, and a numerical simulation predicted commercial-scale performance, which was reflected to the LCM. Life cycle assessment was conducted to assess multiple impact categories, and the potential for deployment in Japan was evaluated, providing feedback to the technology development. Through these processes, the accuracy and granularity of data connecting each scale was summarized.

The water consumption in northern Chilean photovoltaic power: a first approach

Mabel Vega-Coloma

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The significant rise of solar photovoltaic (PV) power in Chile over the past decade has positioned it as a pivotal source of electricity, accounting for 30.1% of national capacity and generating 16,592 GWh in 2023. This growth, however, is constrained by environmental challenges, particularly in the arid northern regions of Chile, characterised by desert-like conditions and minimal rainfall, where solar radiation averages approximately 3,600 kWh/m^2. These factors create a unique opportunity for solar energy development; however, the increasing scarcity of water—exacerbated by changing climate patterns—poses a critical challenge for maintaining panel cleanliness and operational efficiency. This research quantifies the water

requirements throughout the life cycle of solar PV power generation in Chile with an installed capacity over 82 MW, adhering to ISO 14.040-44:2012 standards and employing a cradle-to-gate approach. The study encompasses the entire production chain, including raw material extraction for construction, cell and panel manufacturing, and import as part of the upstream stage, whereas domestic transport, construction works, and operation of the power plants comprise the direct stage, with a functional unit of 1 kWh of electricity delivered to the grid.

The results show the direct stage comprises around 27% of the total average water consumption (641,711 m3/plant). The indirect stage usage is primarily attributed to panel manufacturing at 32%, with support structures consuming 21%, and the extraction and processing of construction materials—such as sand, cement, and both arid and galvanised steel—contributing 20%. Notably, the specific lifecycle water consumption in Chile is quantified at 85 m³/GWh, decreasing to 58 m³/GWh in the Atacama Region, attributable to its high solar radiation levels.

These findings highlight the need for regulated water use in solar PV plants; however, most water consumption occurs outside the country, and addressing global policies for sustainable water management remains essential within domestic development strategies.

Environmental Sustainability of Solar Energy Systems:Comparison of eco-designed solutions of Silicon Heterojunction Technology Solar Panels

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The energy transition is increasing the use of solar energy systems, but their production depends on various raw materials that are at risk of supply disruptions. The Horizon Europe project 'RESiLEX' (Grant No:101058583) aims to research technological improvements along the entire value chain, from the extraction and conversion of raw materials to the optimisation and recycling of photovoltaic (PV) modules. To address the challenge of reducing environmental impact while minimising the use of critical raw materials, innovative eco-designed solutions for silicon heterojunction (SHJ) cells and photovoltaic (PV) modules are being investigated within 'RESiLEX'.

This study aims to evaluate the environmental impact of the eco-designed solutions. The considered alternative cell processing scenarios use less indium and silver than currently available SHJ cells while achieving the same efficiency, but may require additional processes. Regarding PV modules, changes in interconnection schemes, frame, encapsulant and back-sheet were explored. Using life cycle assessment, hotspots were identified and the environmental impacts of the alternative scenarios were compared with current SHJ cells and modules. The EF method was used and data were obtained from the consortium partners and the literature.

Preliminary results show that the alternative scenario can reduce climate change impacts by up to 30% for the life-cycle phase of cell processing, regardless of the need for additional process steps to ensure SHJ cell operation. For PV modules, changing the frame has the highest impact: the wooden alternative to the aluminium frame is favourable in terms of climate change, although the latter option has a lower impact on land use. The second most-impactful modification is the back-sheet, while other changes have less pronounced impacts.

The first results have provided insights for further experimental set-ups. However, further research on circularity and criticality will provide a more complete picture.

Session 2.18: Engineering Composites with LCA-Oriented Methods

Time: Thursday, 11/Sept/2025: 2:30pm - 4:00pm
Session Chair: Tobias Viere, Pforzheim University, Germany
Session Chair: Davide Bonaffini, Hitachi Rail, Italy

Flying with liquid hydrogen: An assessment of CFRP fuel tank manufacturing in the aviation industry and its challenges

Karina Kroos[1], Jens Bachmann[1], Christian Bülow[1], Sabrina Diniz[1], Sebastian Freund[1], Markus Kleineberg[1], Antonia Rahn[2], Steffen Opitz[1]

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Sustainability and how it can be implemented and assessed is a much-discussed topic these days. The aviation sector is responding to these discussions by developing concepts for sustainable aviation, e.g. alternative propulsion technologies such as the use of hydrogen as a fuel. In the context of this technology, carbon fiber reinforced polymer (CFRP) fuel tanks are being considered to store liquid hydrogen (LH2). These developments need to be underpinned by Life Cycle Assessment (LCA) to support decision making from an environmental point of view and to avoid burden-shifting.

When discussing pressure vessels, it is important to note that there are different tank sizes, types, shapes and corresponding manufacturing processes. Types range from all-metal (type 1) to plastic-lined composite tanks (type 4). In the aerospace sector, current research is aiming at the type 5, full composite tank without liner. The systems connected to the tank itself, such as pumps, pipes, heat exchangers, etc. need to be included as well. All these aspects are of great importance when evaluating a hydrogen tank compared to e.g. a metal fuel tank and its periphery.

As part of this research, the manufacturing of a LH2 tank is modelled and evaluated using different data references. Datasets for CFRP production available in LCA databases such as Ecoinvent are compared with a more detailed model using primary data from industrial scale laboratory production of a tank structure. From the results of these assessments, the differences and uncertainties are discussed. Furthermore, different manufacturing processes and scalability approaches are linked to the model. This approach paves the way for the creation of parameterizable LCI data for CFRP production not only in aviation but also in other industry sectors.

Life cycle assessment of curent and novel insulation materials for hydrogen tank in aircrafts

Andrea Pettersen Helåsen, Angela Daniela La Rosa, Sotirios Grammatikos

Department of Manufacturing and Civil Engineering, NTNU Gjøvik, Norway

Hydrogen is considered a potential solution for achieving zero-emission aircrafts. However, there are limited studies on the sustainability of hydrogen tanks and their materials. This study assesses the environmental impact of potential materials for insulation of hydrogen tanks, which is essential to control temperature and boil-off. Four materials were selected based on past and current research: rigid polyurethane (PUR) foam, silica aerogel reinforced with glass fiber (SAGF), nanocellulose foam (NCF) and polymethacrylimide (PMI).

The sustainability assessment was carried out using life cycle assessment (LCA), with a focus on the ma-

terials production. The functional unit was decided by setting certain conditions and using the amount of insulation required to satisfy the conditions. The conditions were set as follows: heat flux to 40 W/m2, T2 to 299K, T1 to 20K, and cross-sectional area to 1m3. The thickness and amount of material could be calculated from this, resulting in four comparable functional units: 6.27g PUR, 0.179g SAGF, 0.150g NCF, 0.172g PMI.

PUR had the highest impact in all categories, except for terrestrial ecotoxicity where NCF had the highest impact. NCF has the second highest impact in all other categories. SAGF had the lowest impact, with more than 92% coming from glass fibers. When looking at global warming potential (GWP) it was found that most of the impact of glass fibers comes from the energy consumed as electricity and heat. From a sustainability perspective, SAGF is the best alternative according to this study.

Acknowledgement

This work is supported and funded by H2ELIOS. (GA no. 101102003)

Some data was received by OVERLEAF project. (GA no. 101056818)

Sustainability assessment for new oil-water repellent biobased coatings applied to food and textile sectors

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AIMEN, Spain

The TORNADO project (Horizon Europe Nº 101091944) aims to develop new organic and hybrid free-toxic water and oil repellent coatings according to Safe and Sustainable by Design (SSbD) criteria. The proposed novel coatings will be PFAS-free.

One of the objectives of the project is to apply safe and sustainable by design (SSbD) chemical and material design principles as guiding strategies in the process design of innovative coatings. Within the project framework, a synthetic route based on functional biomonomers will be developed and produced at laboratory and pilot scale to obtain new bio-based waterborne organic and hybrid coatings, specifically designed for the packaging and textile sectors. For the packaging sector, a multilayer mayo sauce wrapper was selected and for the textile sector, water-repellent garments were considered.

Environmental and economic dimensions are used as decision support tools to evaluate technical alternatives in the project framework. Therefore, LCA and LCC of different routes for coating production have been performed using data from laboratory and pilot scale experiments: monomer production, monomer functionalisation and coating production. These assessments allow the identification of hotspots that need to be addressed in the further development of the coating in order to meet defined sustainable strategies. A cradle-to-grave scope was considered, including different end-of-life management options, defined in a Recyclability by Design (RbD) analysis.

Although the developed coatings show promising results in terms of sustainability compared to their market equivalents, the main hotspots identified at pilot scale are catalyst and energy consumption during the production process. Therefore, special attention must be paid to optimising energy consumption and catalyst dosage in subsequent development steps.

Furthermore, the use of the SSbD framework at an early stage is proving to be a useful decision support tool for selecting between different alternatives that are technically feasible in terms of environmental and economic sustainability.

Assessing the environmental impacts of additive manufacturing with bio-composites at ambient conditions

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The majority of additive manufacturing (AM) technologies, while enabling a quick production of easily customizable objects, often require the operation at elevated temperatures. These high-temperature processes significantly increase energy consumption and environmental impact, limiting the overall sustainability of such technologies. To address this challenge, there is a potential in substituting high temperature demanding materials with organic biocomposites that can be processed at ambient conditions.

Biocomposites, derived from natural or waste materials, offer a promising alternative due to their lower energy requirements during deposition and reduced environmental footprint. For example, waste products from the food industry, such as oyster shells, pistachio shells, or other agricultural by-products, can be recovered and utilized as components in additive manufacturing. These biocomposites not only reduce waste but also contribute to circular economy principles by giving new life to materials that would otherwise be disposed of.

This study evaluates the sustainability of application of such biocomposites in additive manufacturing processes in order to produce small everyday use objects. By analyzing factors such as energy consumption or material impact, the research highlights the potential of biocomposites to enhance the sustainability of AM technologies. Additionally, the feasibility of room-temperature deposition processes is explored, demonstrating the practicality of these materials in reducing production energy requirements without compromising functionality or quality.

The results suggest that biocomposites can play a significant role in the evolution of sustainable manufacturing. While minimizing resource and energy consumption, they also align with global efforts to reduce industrial waste and carbon emissions. This research contributes to a broader understanding of how bio-based materials can be used for additive manufacturing, guiding the way towards more innovative, eco-friendly solutions in everyday applications.

Environmental impacts of partially recycling carbon fibre reinforced high-performance thermoplastics for aerospace composite structures and uncertainty from modelling choices

Jens Bachmann[1], Emma Arussi[2], Fabian Kühnast[1], Karina Kroos[1], Sabrina Diniz[1], Steffen Opitz[1]

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Advanced manufacturing processes such as Additive Manufacturing are considered for future aerospace structures because of their design freedom. They offer a high potential for lightweight construction and corresponding lower environmental impacts during the use-phase as well as reduced material consumption during production phase. Additionally, thermoplastics improve recycling possibilities compared to thermoset composites.

Calculating the potential environmental impacts of cascading material use with Life Cycle Assessment (LCA) is subject to major challenges. Using the example of a carbon fibre reinforced high-performance thermoplastic, the effect of different refresh rates of virgin and recycled materials as well as the number of cycles and their downcycling effects influence the results. Data for the production of new materials like virgin carbon fibres (vCF) and low-volume thermoplastics, for which little or no primary information is available, are a first obstacle. Impact categories such as Global Warming Potential can vary by an order of magnitude depending on the choice background data (e.g. LCA database, Environmental Product Declaration, laboratory measurements or literature). Different modelling principles, including the choice of End-of-Life

formula, further add to the difficulty to produce comparable results.

In this presentation, the focus of the LCA lies on the new material production compared to the steps necessary for the recycling of materials as preparation for the cascading application in a generic aerospace structure, using different refresh rates. Primary data from laboratory trials on a twin-screw extrusion line for pellet production and material refresh are combined with secondary data sources. The influence of background databases and other modelling choices highlights the necessity for sensitivity analysis and transparency when presenting the results.

A comparison of Global Sensitivity Analysis frameworks in the Ecodesign of a carbon fibre bogie frame.

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Designing products and structural components with lightweight materials such as carbon fibre reinforced polymers (CFRPs) can lead to significant weight and emissions reductions over a component's life-cycle. Consequently, as emission and environmental impact (EI) reduction targets grow, lightweighting has become one of the crucial strategies for achieving sustainable product design. However, quantifying the environmental impact of CFRP structures using environmental impact indicators and life-cycle assessment (LCA) methods is challenging due to the lack of reliable life-cycle inventory (LCI) data and inherent uncertainties in material properties. Concerns about the quality of LCI data, particularly regarding the environmental impacts of carbon fiber production, can further complicate assessments.

Global sensitivity analysis (GSA) frameworks can address these challenges by quantifying uncertainties in EIs and improving the reliability of LCA results. Furthermore, GSA can also aid in highlighting hotspots for design improvement and optimization by identifying key inventory and design parameters. This study compares three GSA methods, namely, Monte Carlo, Morris screening and Polynomial Chaos expansion (PCE) to evaluate their computational efficiency and effectiveness in identifying the top ranking design and inventory parameters of a lightweight, single axle CFRP railway bogie frame. The environmental impact of the CFRP frame is quantified using various impact categories including GWP100 and Resource use. The results highlight the most impactful input parameters of the CFRP bogie frame, and the insights gained from this study will enable the selection of effective design strategies in reducing its environmental impact. Additionally, this study emphasizes the importance of selecting appropriate GSA frameworks for robust and sustainable design of a CFRP structure. Finally, this study contributes to advancing the Ecodesign of CFRP structures in the railway industry.

Carbon Fibers Environmental Impacts: Between Recycling and primary production technologies

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The use of carbon fibers has expanded from aerospace to the renewable energy and automotive sectors. As demand grows, there is increasing pressure to develop low-cost, environmentally conscious alternatives due to the energy-intensive production of PAN-based carbon fibers. This has driven the development of alternative production and recycling technologies.

Life Cycle Assessment (LCA) is a well-established method for evaluating environmental impacts, but results across studies are often incomparable due to differences in modeling choices. This study identified 28 articles, containing 56 inventories for both virgin and recycled carbon fibers. After screening based on data source and technology scale, 10 inventories for 10 distinct technologies were selected for harmonization. Harmonizing functional units, system boundaries, and background systems enabled a meaningful comparison.

Among the technologies assessed supercritical hydrolysis, a potential alternative to PAN-based production, had the lowest environmental impact. Pyrolysis, an energy-autonomous process exhibited negative greenhouse gas emissions, albeit resulting in carbon fiber with 80% of the tensile strength of virgin fiber. However, the results are highly sensitive to the technology modeled and the underlying assumptions, which can cause significant variations if these factors are altered.

This work highlights the value of harmonization studies, particularly in emerging fields where numerous studies exist, but comparability is limited due to inconsistent modelling choices. Examples of such fields include natural fibers, perovskite solar cells, etc. Additionally, the study reviewed the state of reproducibility in LCA research in the field of carbon fibers and provided recommendations for improving reproducibility. Future research could leverage these harmonized inventories to compare with other CFs production and recycling technologies.

Ex-ante Life Cycle Assessment of the Coproduction of Two Key Intermediate Aromatic Chemicals from Woodchips

Zizhang Wang[1], Li Shen[1], Jorge Bueno Moron[2], Gerard van Klink[2], Martin Junginger[1]

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Aromatics are a group of high-value chemicals essential to various polymers and products. Currently, aromatics are predominantly derived from fossil resources. Their alternative synthesis from biomass is seen as a promising strategy to reduce such overreliance on fossil fuels while prioritising the high-value application of biomass resources. To further upscale and optimise these emerging synthesis technologies, a better understanding and more data-informed evidence of their environmental sustainability are required.

This study presents a cradle-to-gate ex-ante life cycle assessment of the coproduction of two key intermediate aromatic chemicals, namely methoxymethylfurfural and furfural, derived from residual woody biomass. The main objectives are to quantify environmental impacts across seven key categories, identify hotspots, and provide recommendations for future process optimisation.

The results indicate that the supply of energy and cooling water for chemical separation is the dominant contributor, accounting for at least 57% of the total environmental impacts across all categories. This dominance highlights the significant potential for impact reduction through a cleaner energy supply, as evidenced by the assumed 2030 scenario; however, achieving this potential requires further research on detailed

projections of the future industrial heat supply mix.

Carbon flow mapping reveals that the coproduction technology can retain up to 91% of carbon in its main and by-products with minor direct emissions; nevertheless, the high carbon content in process wastewater highlights the need for more optimised wastewater treatment strategies in such biorefineries. An alternative scenario examining the treatment of humins shows that the environmental burdens associated with their production outweigh the benefits of energy recovery from their incineration, emphasising the need to identify high-value applications of humins. Compared to a conventional furfural production, this innovative route generates much lower environmental impacts, because of less energy-intensive reactions and less resource-intensive biomass cultivation.

Session 2.19: Digital Product Passport: Information Access for Sustainable Consumption

Time: Thursday, 11/Sept/2025: 4:30pm - 6:00pm
Session Chair: Lucyna Lekawska-Andrinopoulou, Institute for Communication and Computer Systems, Greece
Session Chair: Kostas Chatziioanou, ICCS, Greece

Dynamic Digital Product Passports: Advancing Circularity and Sustainable Innovation in the Steel Industry Supply Chain.

Stella Georgali, Lucyna Lekawska-Andrinopoulou, Kostas Chatziioannou, Thodoris Theodoropoulos, Georgios Tsimiklis, Angelos Amditis

Institute of Communication and Computer Systems, Greece

The steel industry's value chain is being transformed through innovative digitalization aimed at achieving sustainability, decarbonization, and operational excellence [1]. Central to this transformation is the development of dynamic Digital Product Passports (DPPs), which offer comprehensive, continuously updated repositories of product data across a product's lifecycle. By addressing critical information gaps, DPPs facilitate efficient data exchange among stakeholders, promote informed decision-making, optimize resource use and lifecycle management while enhancing process efficiency.

This work explores the technological enablers, challenges, and regulatory considerations involved in adopting DPPs, highlighting their transformative potential in creating a more transparent, sustainable, and traceable steel supply chain. It serves as preparatory research for the development of a dynamic DPP, including testing activities with actual stakeholders within the steel supply chain, aimed at empowering consumers with more informed decision-making. The dynamic DPPs will aggregate real-time data on material properties, production processes, and sustainability metrics, enabling seamless information exchange among steelmakers, end-users, and other stakeholders through an industrial dataspace. Live traceability methods embedded within DPPs will provide greater transparency and resource optimization within the steel supply chain, aligning with the Ecodesign for Sustainable Products Regulation [2], which mandates transparent lifecycle documentation to advance circular economy practices. A key aspect of this work's DPP effectiveness lies in the integration of advanced in-line sensors, which monitor and capture critical data during production. Sensor fusion techniques and deep learning models, empower stakeholders to make better-informed decisions, improve product quality, and enhance lifecycle circularity.

This research is supported and funded by the Horizon Europe program under Grant Agreement No: 101178919 (SMARTChain).

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A manufacturers experience: EPD as "PDF anno 2018" to EPD as "DPP anno 2025"

Knut Jøssang

Pipelife Norway, Norway

This paper presents the journey of Pipelife Norway from publishing Environmental Product Declarations (EPDs) in static PDF format to enabling machine-readable Digital Product Passports (DPPs) in alignment with the 2025 digital construction landscape.

It explores how EPDs, traditionally used for environmental transparency, are evolving into structured digital assets that integrate with Building Information Modeling (BIM) and support Life Cycle Assessment (LCA) and procurement. Through early adoption of data standards like ISO 23386, ISO 23387, and ISO 22057, Pipelife has structured its product and environmental data to enhance interoperability and automation across construction workflows.

The case highlights technical and governance challenges - such as data quality, semantic consistency, and the "BIM gap" - that hinder industry-wide adoption. It also addresses the limitations of current Product Category Rules (PCRs) and the need for scalable EPDs for composite products. Ultimately, the study demonstrates that structured environmental data is critical to enabling environmental, transparent, and circular construction practices, and suggests that upcoming DPP requirements may serve as a unifying framework for digital transformation in the sector.

Promoting Environmental transparency to answer regulators and customers data needs

Bruno Lomba, Nina Macard, Amandine Louise, Benjamin Martinez

Schneider Electric

European Union regulatory initiatives such as Green Claims Directive, Ecodesign for Sustainable Products Regulation through the Digital Product Passport, aiming at empowering consumers, advancing product sustainability and transparency while preventing greenwashing, are accelerating. Companies from every industry are facing increasing calls from their customers, investors, and employees to play a greater role in accelerating the transition to more sustainable business practices. To advance these goals, at Schneider Electric we have undergone an evolution on our approach to product transparency and accountability by transitioning from using a proprietary label to adopting the Environmental Data Program, a new transparent, data-based framework, offering increased transparency on environmental product attributes.

We propose to present how this framework will enable us to anticipate upcoming regulations such as the Green Claim Directive and ESPR: which data we are disclosing and how, as well as how we support the digital major shift of the Product Passport.

Additionally, we will present how this program further aims at empowering organizations to make better-informed purchasing decisions including on circularity, support aftermarket services, streamlining their reporting, and differentiating their value proposition. This approach gives the opportunity to tailor environmental data to each product and application to raise customer awareness on specific ecodesign levers making sense into their system. Finally, we will share how we are using it internally as a key enabler to industrialize circular-led design products and support transparent and responsible marketing and communication practices.

Potential and challenges of Digital Product Passport in hydrogen supply chain

Akrivi Korba, Lucyna Lekawska-Andrinopoulou, Kostas Chatziioannou, Georgios Tsimiklis, Angelos Amditis

Institute of Communication and Computer Systems (ICCS), Greece

As the hydrogen economy grows, ensuring transparency, traceability, and sustainability across the supply chain is essential [1]. Digital Product Passports (DPPs) could provide data on origin, production processes, and environmental impacts, allowing stakeholders to verify sustainability and carbon footprints [2]. By including carbon intensity, and production methods (e.g., green, blue, or gray hydrogen), DPPs could facilitate hydrogen's integration into energy systems, regulatory compliance, and decision-making [3].

This study explores a Hydrogen DPP to manage and verify critical data across the hydrogen value chain. It will include details like hydrogen origin, production methods, carbon intensity, transportation, and physical properties, enhancing sustainability, tracking and interoperability.

Key user groups—producers, transport operators, regulators, and consumers—were engaged, revealing demand for a streamlined tool. A questionnaire collected insights on lifecycle carbon intensity, regulatory compliance, and accessibility.

Expected outcomes include a Hydrogen DPP concept prioritizing traceability and operational efficiency. Challenges include establishing secure data-sharing mechanisms and aligning with regulations [4].

Next steps involve refining the DPP concept based on feedback and addressing gaps. A prototype will demonstrate usability and benefits in the hydrogen supply chain.

The Hydrogen DPP offers potential to improve sustainability, supporting a low-carbon economy. Overcoming challenges will be critical.

This work is supported and funded by Horizon EU (GA No: 101138473).

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Product passport for traceability and environmental responsibility: a pilot experiment in the WEEE sector

Xavier Lantoinette, Amélie Gombeaud, Laurène Cuénot

ecosystem, France

ecosystem is a French Producer Responsibility Organization (PRO) which organizes and manages the collection, repair, reuse and recycling of Waste of Electrical and Electronic Equipment and Batteries.

In January 2025, to anticipate the DPP (Digital Product Passport) from ESPR regulation, ecosystem launched a large-scale two-year Product Passport pilot. It involves producers, retailers, repairers and stakeholders from social economy for reuse in France. Through a shared, open-source infrastructure, the project

aims to extend the lifespan of household appliances, to enhance product's traceability and environmental responsibility.

During this pilot phase, the objective is to trace about two million appliances with their unique passport at different stages of their lives. This will allow the stakeholders to track the device's status at key stages as manufacturing, sell, repair, reuse or end-of-life. Extending passports to products throughout their lifecycle at a large-scale boosts transparency and circularity. It helps tracking a product's history, fostering consumer trust in refurbishment and resale. This approach supports circular economy by extending product lifespans and thus reducing waste.

ecosystem will be able to consolidate key data - specifications, repairs, and environmental impact - into an accessible record that will ensure continuity and benefits all stakeholders.

For this initiative to be viable on a large scale, it requires a non-proprietary, interoperable system that allows all stakeholders to share and access the data securely. A blockchain system was chosen.

Regarding the large amount of data generated by the pilot, a dedicated working group will ensure effective governance of the data and the platform.

Finally, an entire section of the experiment will be dedicated to screening the environmental performance of the solution developed as regards to the avoided impacts of extending the lifetime of products.

ecosystem will remain synchronized and aligned with European projects and normalization processes.

Standardisation as enabler of digitalisation

Anne Rønning[1], Aitor Aragón[2], Oscar Nieto[2], Espen Schultze[3]

[1]Norwegian Institute of Sustainability Research, Norway; [2]Universidad Politécnica de Madrid, Spain; [3]Cobuilder International

The European Union (EU) has established in 2024 ambitious requirements through regulations such as the Ecodesign for Sustainable Products Regulation (ESPR) and the new Construction Products Regulation (CPR). While the ESPR applies its requirements across multiple industries, the CPR adopts a sector-specific approach, addressing the unique challenges and demands of the construction industry. Both frameworks necessitate a holistic approach to ensure that construction products are designed, installed, utilized, and recycled sustainably.

Under the new CPR, manufacturers will be required to issue a Declaration of Performance and Conformity for any construction product covered by a harmonized technical specification before it can be placed on the market. This declaration includes not only traditional technical characteristics but also environmental data, which should be based on the Environmental Product Declarations (EPDs) according to EN 15804, a European standard defining the methodology for calculating the required environmental characteristics. EPDs are essential for accurately assessing the environmental impact at the building level according to EN 15978. EN ISO 22057 defines the data templates to integrate EPD-data in BIM, ensuring the use of this information for the LCAs at asset level.

To meet information requirements for construction products, including environmental data, such information must be accessible via Digital Product Passports (DPPs). DPPs are pivotal in providing comprehensive details about a product's lifecycle, including its origin, materials, production methods, environmental impact, repairability, and recyclability.

This paper highlights how machine-readable and machine-interpretable data, based on international and European standards, serve as the foundation for DPPs. It further emphasizes the importance of data templates and dictionaries as key enablers in this context, ensuring interoperability between DPP, EPDs and BIM as primary data sources. This interoperability is crucial for advancing the digitalization of LCAs for buildings and accelerating the transition towards sustainable construction practices.

A Unified Approach to Life Cycle and Circularity Assessments: Framework Development for Circular Transition

Ajay Kumar, Annik Magerholm Fet

Norwegian University of Science and Technology, Norway

The European Green Deal aims to establish a resource-efficient and competitive economy with net-zero emissions by 2050, decoupling economic growth from resource consumption. Additionally, the Eco-design for Sustainable Product Regulation (ESPR) and Corporate Sustainability Reporting Directive (CSRD) require companies to report on their sustainability and circularity impacts. Businesses will soon be mandated to develop Environmental Product Declarations (EPDs) and Digital Product Passports (DPP).

ISO 14040 and ISO 14044 provide standardized methodologies for calculating environmental impacts, while various approaches for circularity assessment have been developed, including the ISO 59020 standards from 2024. Recent research has explored frameworks that integrate sustainability and circularity assessments. Furthermore, ISO 59010 outlines a framework that defines the transition phases businesses must navigate to achieve circularity. These advancements present significant challenges for businesses, requiring them to balance sustainability and circularity with profitability.

A systems engineering approach is a structured methodology used to design, develop, and manage complex systems throughout their life cycles. It integrates multiple disciplines to ensure that all components function cohesively to achieve defined objectives, with an emphasis on requirements, modelling, and validation.

This study proposes a conceptual framework that incorporates the systems engineering approach while integrating the methodologies outlined in ISO 14040, ISO 14044, and ISO 59020 to refine the framework for business transition. The proposed framework aims to minimize redundant data collection for life cycle assessment (LCA) and circularity assessment (CA) at both the product and organizational levels. The framework is expected to enable businesses to utilize standardized data sheets for generating EPDs and DPP while also offering actionable insights for enhancing circularity and sustainability across upstream and downstream life stages.

Systematic Literature Review and Conceptual Framework for Digital Material Passports to enable Circular Economy

Malina Wiesner[1], Joanna Steiner[1], Janine Mügge[1], Achim Hoffmann[2], Sebastian Szczepanski[3], Marvin Manoury[1], Kai Lindow[1]

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The transition to a circular economy demands robust mechanisms to manage and exchange material information across complex supply chains. Digital Material Passports (DMPs) and Digital Product Passports (DPPs) are key enablers, providing transparency and traceability throughout the lifecycle of materials and products. While DPPs focus on product-level compliance with regulatory frameworks like the ESPR, DMPs are essential for implementing a circular economy, as they address requirements at a granular material level and support different R-strategies (e.g., reuse, recycling).

This paper systematically reviews the literature and analyzes existing solutions to identify requirements for material information and strategies for their exchange. Initiatives such as Catena-X and CIRPASS are examined to explore how data spaces and digital infrastructures support seamless material information.

Input from industry experts with expertise in material data and information exchange, grounded in current processes and requirements, offers practical insights into challenges and opportunities for effective data-sharing solutions. The research identifies cross-sectoral requirements and transferable approaches

across industries, including automotive and aerospace industries. By aligning insights from academia and industry, this work contributes to the discourse on leveraging DMPs to support circular economy.

The results present a conceptual framework defining DMPs within broader DPP ecosystems, emphasizing digital continuity and standardized data exchange. It highlights the synergy between DPPs and DMPs in meeting regulatory demands and advancing transparency across complex supply chains. By addressing material-level transparency and interoperability, this study outlines actionable pathways to enable circular economy across supply chains. Future research directions include sector-specific adaptation and the pre-requisites for DMP implementation. Integrating DMPs with DPP systems has the potential to bridge data gaps and enhance lifecycle transparency, particularly at critical stages like end-of-life processes.

Session 2.20: Life Cycle Based Tools and Data Science Interactions Part II

Time: Thursday, 11/Sept/2025: 4:30pm - 6:00pm
Session Chair: Monia Niero, Sant'Anna School of Advanced Studies, Italy
Session Chair: Alessandro Manzardo, University of Padova, Italy

Automated Estimation of Clothing Information for Evaluating Environmental Impact

Sumiaki Kusahata[1], Dami Moon[2], Yoshihiro Kawahara[1]

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This study aims to evaluate the efficacy of ChatGPT, a large language model (LLM), in automatically estimating parameters crucial for calculating greenhouse gas (GHG) emissions. In doing so, we explore the potential applications and future directions of ChatGPT in environmental impact assessments. As environmental concerns intensify, there is a growing demand for quantifying and clearly disclosing the environmental impacts of products and services. LLMs, trained on vast amounts of textual data, have emerged as promising tools for effectively collecting and extracting necessary information

Our research investigates the feasibility of using ChatGPT to extract relevant parameters for accurate GHG emission calculations. We focused on secondhand clothing items listed in the Japanese online flea market. ChatGPT was employed to extract data such as size, material composition, washing methods, and frequency of use from information provided by sellers, including product images, descriptions, and specifications. In a preliminary analysis, a sample of 50 tops (men's and women's) were selected, and estimates were made for size, laundry methods, and ingredients. Excluding items that could not be estimated, the accuracy of our estimates was 29/32 (91%), 12/12 (100%), and 12/14 (86%), respectively. We plan to expand this analysis to 3,500 samples for a more comprehensive accuracy assessment to facilitate the GHG emissions calculations.

This study highlights the potential of AI technology in environmental impact analysis. Future steps include extending the research to other product categories, such as electronic devices, to verify broader applicability. Additionally, we will explore how this technology can contribute to extracting product information that enhances trust in consumer-to-consumer transactions. Ultimately, our research seeks to revolutionize data management and digitalization in life cycle assessment by thoroughly validating the effectiveness of AI technology in quantifying environmental impacts and providing reliable information.

Combined use of information technology and life cycle thinking tools to assess the performance of healthcare waste management options

Filomena Ardolino[1], Francesco Parrillo[1], Michele Monaco[1], Chiara Raucci[1], Martina Bellopede[1], Carlo di Domenico[2], Umberto Arena[1]

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Life Cycle Management (LCM) tools is a valuable support for organizations and decision-makers, to design and implement sustainable solutions along products value-chains. On the other hand, they require large amounts of high-quality data and information, which must be appropriately processed. These time-expensive activities can be facilitated by information technology (IT) by providing fast and systematic data gathering and analysis.

This study investigated the synergies deriving from coupling Environmental Life Cycle Assessment (and,

then, Life Cycle Costing) with an IT. The resulting IT-LCM package could be applied to remarkably improve the overall sustainability of Healthcare Waste Management (HCWM) in hospitals and smaller healthcare facilities. The sector generates high environmental and economic impacts, despite its primary mission should be enhancing the human well-being. HCWM must operate with a wide range of materials (including sharps, human body parts, medical devices, chemical and pharmaceutical waste) generated from treatment, diagnosis, and immunization procedures, all requiring specific treatments and handling protocols. An upgraded management scheme of these wastes is urgent, together with the necessity of a reliable quantification of its sustainability and an easier and economically viable implementation.

Final aim of the study is investigating how an existing IT system can be adapted to collect and process comprehensive information and data - in terms of generated flowrates, contained fractions, and applied treatment options – to improve HCW monitoring and traceability. The possible connections between the IT system and E-LCA have been analysed, in the perspective of a fast achieving of reliable data to evaluate the performance of different HCW management options. The study first proposed a taxonomy of the HC wastes, then implemented a technology mapping of the current safe and reliable treatments. Preliminary results, obtained for a selected HCW, allow identifying main areas of concerns and those where cost savings and environmental benefits can be achieved.

Dynamic GHG assessment of electricity use enhancing representativeness of results and forecasting GHG intensity of European electricity mixes enabling automated decision-making on time-flexible energy-intensive operations

Alexander Kirsten[1], Hanmin Cai[1], Ekaterina Aymon[2], Ivan Kostanjevec[2], Jean-Paul Calbimonte[2], Didier Beloin-Saint-Pierre[1]

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Greenhouse gas (GHG) emissions related to electricity use can significantly contribute to organisations' overall carbon footprint (CF), especially if linked to energy-intensive activities. Fossil energies are currently the main drivers of GHG emissions in electricity mixes. The expansion of renewable alternatives can effectively decarbonise these mixes but has the disadvantage of intermittent production, which doesn't fit with current electricity consumption habits. Life Cycle Assessment (LCA) tools and data science strategies can help to steer electricity demand to periods when electricity is mainly produced by renewables that lower GHG intensities.

To address this challenge, we have built a solution based on the EcoDynElec Python package that uses historical electricity data from ENTSO-E FTP servers providing temporal profiles of GHG impacts of electricity mixes of most European countries since 2014. These profiles provide data up to a 15-minute resolution while respecting the standard structure of electricity models in LCA databases (i.e. mix = production + imports). This information is used to train machine learning (ML) algorithms to create a forecast of these electricity mixes' CF of 48 hours in advance – also at 15-minute resolution. Such services are comparable to the electricitymaps.com application programming interface (API) service, with the added adaptability to be consistent with different assessment standards (enabled by EcoDynElec). We then integrate the historical and forecasting services within a web-based dashboard of the WISER project. Combined with uploaded electricity consumption data, we can significantly enhance the representativeness of GHG assessment results based on dynamic LCA. The average annual GHG value is substituted by a value specific to the amount and type of electricity consumed within a specific timeframe.

Organisations handling energy-intensive time-flexible operations (e.g. data centres) could use the forecasting for automated decision-making processes that might significantly help to reduce energy-related GHG emissions (e.g. scope 2).

AI-Driven Wastewater Treatment LCA Dataset: High Precision, Dynamic Updates, and Regional Applicability Study

Zhijun GUI, Fan Wang

Shanghai E-Carbon Digital Technology Co., Ltd, China, People's Republic of

As global sustainable development initiatives progress, Life Cycle Assessment (LCA) for wastewater treatment has become pivotal for evaluating environmental impacts and supporting informed decision-making. However, current LCA datasets face significant challenges regarding completeness, regional applicability, and data quality due to regional heterogeneity and data fragmentation. This paper presents an advanced AI-based LCA tool designed to construct a high-precision, dynamically updated dataset for wastewater treatment in China, enhancing its applicability in various scenario analyses. The study divides dataset construction into three main modules: 1) Differences in water quality before and after treatment, leveraging deep learning models to quantify the purification efficiency of treatment processes; 2) A regional treatment process repository, encompassing common and emerging technologies such as oxidation ditches, activated sludge processes, and membrane bioreactors (MBR), forming an efficiently accessible process dataset; 3) Integration of regional climate and policy variables, including climate factors (e.g., water evaporation effects due to high temperatures) and policy impacts (e.g., differing wastewater treatment coverage between urban and rural areas).In the data collection and processing stages, this research incorporates AI technologies to enhance data accuracy and completeness. Specifically, machine learning and natural language processing (NLP) are employed for automated data extraction and gap filling, deep learning models are used for spatiotemporal data interpolation, and AI-driven anomaly detection and multi-source data fusion ensure data reliability and consistency. The results of this study facilitate the efficient generation of LCA datasets, providing unprecedented support for precise environmental impact analyses and cross-regional policy evaluations in wastewater treatment.

Unlocking regionalization in ecoinvent: harnessing trade data for accurate life cycle assessments

Maxime Agez, Elliot Muller

CIRAIG, Canada

Imagine having a more precise and comprehensive understanding of regional production and consumption patterns within the ecoinvent database. By leveraging trade data from sources like UN COMTRADE, we can make this a reality.

Our approach involves:

1. Identifying key producers: For each product in ecoinvent, determine its main countries of origin in the current market, such as butanol produced mainly in South Africa and China.

2. Regionalizing processes: Create localized versions of production processes, like butanol production in China, based on closest available equivalents (e.g., RoW) and adapting essential inputs like electricity, heat, and waste treatment to the local context as well as spatializing the elementary flows to the process' region.

3. Connecting to the global market: Link these regionalized processes to the broader ecoinvent database, establishing connections like China's propylene consumption market (an input of butanol production), whi-

ch can be informed by trade data.

By integrating trade data, we can:

- Enhance regionalization within ecoinvent

- Improve accuracy and representation of global supply chains

- Support more informed decision-making and sustainability assessments

This project called "regioinvent" fits this session as it integrates multiple sources of data together. Although it has no link to artificial intelligence, digital technologies or big data (in the IoT sense of the term), regioinvent is a life-cycle based tool that improves the impact assessment modelling (thanks to the regionalization of impacts) and enhances the accuracy of impact assessment results (thanks to the better representation of supply-chains through trade data). Companies will benefit from the increased accuracy provided by regioinvent directly in their LCAs, as the transition from an ecoinvent-based modeling to a regioinvent-based modeling is seamless.

Challenges and benefits of EPD automation – a review

Greta Bacchelli[1], Marco Tomasoni[1], Luca Marcolongo[1], Gabriele Campadello[1], Seila Rodriguez-Vilches[2]

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Environmental Product Declarations (EPDs) are public, third-party verified environmental declarations that communicate the environmental impacts related to a product or a product family. The request to cover an increasing number of products with EPDs implies making EPD generation process quicker and smarter. Therefore, automation of EPDs is on the rise, reducing costs and time compared to the standard process. The aim of this contribution is to provide a general overview of the available EPD generator tools, as well as identifying the challenges of adapting EPD tools to different industrial sectors.

The outcome of the state-of-the-art investigation is that the largest percentage of the tools focuses on construction products (mainly concrete and cement), and the rest of the tools under review focuses on different categories of products (e.g., electricity distribution, lightning). However, EPDs are being extended as license to operate to a whole range of other industrial sectors, and not all have the same level of complexity both in products and in the organization.

Therefore, EPD tools, as well as manufacturing corporations, could upgrade their approach to EPD automation. EPD tools would need to improve flexibility in the database creation process and in the long-term maintenance of data. Additionally, the pre-verification of the tool is a crucial requirement to ensure a significant cost and time reduction in the EPD generation process. On the other hand, companies need to set a structured team to support the implementation of an EPD tool (e.g., involvement of IT experts for data). But most of all, companies need to upgrade the availability and quality of manufacturing data: product and factory data need to be up-to-date and easy to retrieve; this is a basic requirement to implement a true automation, possibly envisaging API connection with the EPD tool.

Life Cycle Footprinting Tool for the Pharma Sector

Peter Shonfield, Chris Poulopoulos, Vicky Norton

Environmental Resources Management Ltd ('ERM'), United Kingdom

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, and meeting requests for information from customers, such as healthcare providers, amongst others.

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 reducing significantly 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.

A Web-Based Tool for Visualizing and Navigating the Complex Landscape of Life Cycle Assessment Standards and Regulations

Alexander Schneider[1], Felix Funk[1], Paria Amiri[1], Shadi Khamseh[1], Katrin Helm[2], Jonathan Fuchs[1], Tobias Reichenstein[1], Florian Ansgar Jaeger[3], Jörg Prof. Dr.-Ing. Franke[1], Johannes Wunderlich[4], Filipe Sundfeld Veloso[4]

[1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany; [2]Technische Universität Berlin; [3]Digital Industries Siemens AG; [4]Siemens AG

Life Cycle Assessment (LCA) analysts are often faced with the challenge of navigating through the diverse and continuously changing landscape of standards and regulations due to continuously increasing political requirements. Standards such as the GHG Protocol, ISO 14067, and ISO 14025 define specific requirements for environmental impacts and carbon footprints, complicating the consistent application of LCA. Additionally, industry-specific standards from sectors like chemicals, construction, transportation, and food further add to the complexity. Until now, no interactive solution has integrated these diverse data sources and provided an intuitive way to visualize their interconnections.

This paper presents a web-based tool designed to visualize and analyze the complex requirements of around 500 different standards, guidelines, and norms in LCA. The tool offers a comprehensive, user-friendly platform that facilitates informed LCA and sustainability analysis. It allows users to examine the relationships between different parameters, considering international as well as industry-specific standards.

Developed in Python, the tool transforms large, complex datasets into visually intuitive structures using the Fruchterman-Reingold algorithm. By positioning nodes (e.g., products, processes, and standards) according to their relationships, it makes clusters and trends more apparent. Users can customize the visua-

lization by filtering data, adjusting node sizes, modifying edge weights, and highlighting subgraphs. This interactivity fosters the discovery of critical patterns that are essential for optimizing life cycle management and supporting sustainable decision-making.

The tool will be published on the Estainium website (www.estainium.eco) and will provide valuable support to users and researchers in the field of LCA. This paper describes the design, methodology, and application of the tool, highlighting its potential to streamline LCA processes and enhance the quality of sustainability analyses.

The use of novel plant modelling approach to support LCA tool development for sustainable chemicals production

Samuel Sanchez[1], Luis Gamez[2], Angel Vergara[1], Elena Uldall[2], Ceren Imren[1], Yannick Bernard[1], Martijn Gipmans[1]

[1]Sphera Solutions GmbH, Germany; [2]Moeve Chemicals, Spain

The chemical industry faces a significant challenge in developing and producing more sustainable chemicals. One notable innovation addressing this challenge is NextLAB, a Linear Alkylbenzene (LAB) that incorporates certified renewable raw materials and can be up to 100% based on renewable materials. Linear Alkylbenzene is a widely used chemical in detergent and surfactant industry. NextLAB incorporates alternative raw materials to enhance sustainability. However, the use of alternative raw materials and energy supply may increase the complexity of modelling a cradle-to-gate system boundary. We have developed a novel approach for generating footprint results for all products produced at one complex production site. The approach combines a highly parametrized LCA Model for a complete chemical production site (LCA Site Model) with a digital LCA tool for data input. The solution integrates data available at site level such as utilities consumption with product-specific data. Such a LCA tool will allow for a more convenient and consistent data collection and eventually can be integrated into a fully automated LCA solution. The LCA tool also enables the calculation of the carbon footprints of products made from bio-based raw materials and assesses the impact of using renewable feedstock as well as renewable energy compared to traditional products. Therefore, this LCA tool will allow to understand the impacts of business decisions a priori and support the decision-making process for new product designs. The LCA Site Model and LCA tool developed for the chemical production site site located in Puente Mayorga in Spain will be demonstrated, discussing the challenges and achievements of developing and using such a tool within a large multi-national organization.

Session 2.21: Evaluations of Circular and Low Carbon Plastic Value Chains towards sustainability Part II

Time: Thursday, 11/Sept/2025: 4:30pm - 6:00pm
Session Chair: Christian Krüger, BASF, Germany
Session Chair: Tomas Ekvall, Tomas Ekvall Research, Review & Assessment (TERRA), Sweden

Life Cycle Assessment of PVC Recycling: Expanding Recyclable Fractions through the CIRC-PVC Project

Jean Metzmacher, Angélique Léonard

University of Liège, Belgium

In the construction and demolition sectors, plastic waste management is often inadequate, making plastics recycling a significant challenge. A large proportion of plastic waste remains unprocessed, leading to high rates of incineration and landfill disposal. This is especially true for PVC, one of the most widely used plastics worldwide.

Current mechanical recycling technologies have some limitations. They cannot effectively handle certain types of PVC, particularly those from older products that contain harmful additives. Additionally, composite PVC structures present challenges in mechanical recycling, as the process fails to separate and recover these materials effectively. This often results in their downgrading to lower-quality applications.

To address these issues, the CIRC-PVC project proposes a novel chemical recycling technology capable of extracting harmful additives from old PVC compounds and processing composite structures, thereby expanding the range of recyclable PVC types. A Life Cycle Assessment (LCA) has been integrated into the project as a critical decision-support tool. The LCA focuses on quantifying the environmental impacts at each stage of the recycling process and comparing the environmental performance of recycled PVC to that of virgin materials.

The CIRC-PVC project aligns with climate change targets and reflects the evolving European legislative framework, which increasingly supports recycling initiatives and imposes stricter requirements. By improving PVC recycling practices, the project not only helps reduce plastic waste and lower greenhouse gas emissions but also supports the European commitment to a circular economy.

Defining and addressing the allocation problem at recycling

Tomas Ekvall

Tomas Ekvall Research, Review & Assessment (TERRA), Sweden

The distinction between attributional and consequential LCA can be used to structure the debate on how to define the allocation problem and model recycling. Attributional allocation problems involve processes in the life cycle of the material. These include recycling processes, but can also include the primary production and (possibly) the final waste disposal of the material that is recycled. From a consequential perspective, modelling of recycling instead focusses on the consequences of recycling. These include increased emissions from recycling processes, but also avoided emissions from the production of substituted materials and (ideally) from the avoided waste treatment. The consequential allocation problem concerns how to allocate (sic!) the consequences of recycling to the products where the material is used.

Cut-off approaches fit in attributional LCA since they disregard the avoided impacts of substituted material production. End-of-life approaches can be divided into closed-loop and substitution approaches. When recycling is modelled as a closed loop, it reduces the primary production of the recycled material. This fits

in an attributional LCA. Substitution approaches instead should include the avoided production of the material that is known or reasonably assumed to be substituted. This fits in a consequential LCA. Closed-loop and substitution approaches can give very different results, for example when recycled plastics replaces wood.

The Circular Footprint Formula is consequential because it involves the assumed substitution. Other approaches to modelling recycling can, in a similar way, be defined as attributional and/or consequential. However, most approaches thus defined as consequential still disregard consequences that are sometimes important, for example how the use of recycled material affects alternative waste management of this material, or how the substitution of a different kind of material (e.g., wood for plastics) affects the waste management of the product where the recycled material is used.

Designing novel bioplastics and their supply chains within planetary boundaries

Marie J. Jones[1,2], Arthur Chuat[1], Matthieu Souttre[3], Vibhu Baibhav[1], Jana Lukic[1], Manuele Margni[3,4], Jeremy S. Luterbacher[2], François Maréchal[1]

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Biomass is a promising renewable feedstock for the chemical industry, yet current processes that retrofit biobased molecules into petrochemicals suffer from low biomass utilization efficiency, limiting environmental sustainability and exacerbating pressures on biodiversity, water, and land resources. Recent developments in alternative bioplastics that mimic the properties of PET—the primary plastic used in packaging—aim to address these issues by retaining as many biogenic atoms as possible in native-like structures [1]. To guide the formulation of these new products, we assess the prospective environmental impacts of PET-replacement bioplastics and propose design targets to minimise the transgression of the planetary boundaries (PB).

We integrate biorefinery process models, and their supply chains, into a continent-wide energy system model, which includes a blueprint of Europe's industrial sector, to analyse resource competition between biorefineries and the existing industry [2]. To prevent shifting environmental burdens, we conduct a holistic environmental impact assessment by mapping 16 mid-point indicators of the Environmental Footprint method to PBs, downscaled to the European industry with various socio-economic methods.

For novel bioplastics, a one-to-one mass substitution with petrochemical counterparts may not be feasible. The environmental impacts of new molecules must be evaluated considering use-phase functions, which depend on tuneable material properties such as gas and water resistance and mechanical strength. Preliminary results indicate that while the novel bioplastics significantly reduce contributions to climate change, they may disrupt the freshwater cycle if increased electricity demand is met primarily through hydropower. Optimizing energy systems in synergy with production supply chains offers pathways for a future European chemical industry that aligns with both environmental and societal constraints.

[1] Manker, L. P. et al. Nat. Chem. 14, 976–984 (2022).

[2] Girardin, L. et al. Proceeding of ECOS 2023.

Plastic footprint: definition and operationalization

Elena Corella-Puertas[1], Nadim Saadi[2], Martina Gallato[3], Magnus Fröhling[1], Anne-Marie Boulay[2]

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The ongoing negotiations of the UNEP Intergovernmental Negotiating Committee for achieving a global, legally-binding treaty to end plastic pollution have shown there is an urgent need for science-based, quantitative tools for assessing the potential impacts of plastics and their alternatives. To develop the needed environmental decision-making tools, the international committees PFN (Plastic Footprint Network) and MarILCA (Marine Impacts in Life Cycle Assessment) were founded.

The PFN and MarILCA committees are collaborating to develop a joint definition of a "plastic footprint", with the goal to harmonize tools and efforts for quantifying plastic pollution. For the product and the corporate levels, the plastic footprint methodology includes the quantification of the leakage and potential impacts of plastics, and is compatible with life cycle assessment (LCA) methodologies. A quantified plastic footprint is essential for setting targets to tackle plastic pollution.

To operationalize the plastic footprint and provide guidance to LCA practitioners, the PFN and MarILCA committees deliver specific modules for the quantification of different types of plastic leakage (macro- and microplastics into different environmental compartments) and, recently, a first module on the potential impacts of microplastic leakage to aquatic environments was completed. The latter methodology links the microplastics inventory with the impact category of physical effects on biota at the midpoint and endpoint level – this impact category was first introduced by MarILCA and includes physical impacts of plastics through external (entanglement, smothering) and internal (ingestion) pathways. The methodology was applied to a case study of a polyester T-shirt, allowing to quantify the microfiber leakage at different life cycle stages and assess the relative importance of physical effects on biota impacts compared to other impact categories.

Overall, the presented plastic footprint definition and operationalization will provide valuable input for policy-makers, industry and academia in the journey to end plastic pollution.

Advancing Sustainable Food Packaging: Life Cycle Assessment of PHBV Bioplastics in the ViSS Project Using the SSbD Framework

Inka-Mari Sarvola, Katri Behm

VTT, Finland

The progressive substitution of fossil-based consumer plastics products with bioplastics is crucial to decarbonise our society, while also biodegradability of the new bioproducts has to be ensured. The EU-funded Horizon-project ViSS aims to create a safe, sustainable, fully functional and highly replicable circular value chain of PHBV bioplastic specifically for high performance food packaging, utilizing food industrial residues as carbon and nutrient sources for PHBV production. The technology development of ViSS follows Safe and Sustainable by Design framework (SSbD) established by EU. This presentation will detail the methodology, results, and findings of the first life cycle assessment (LCA) iteration.

SSbD framework facilitates a (re-)design approach to create products, that are genuinely safe and sustainable, rather than merely relatively safer and more sustainable than alternative products. It involves three iterative assessment phases, evaluating safety and environmental sustainability, and optionally also socio-economic sustainability. Based on the results of the assessments, the product is re-designed and improved. In ViSS, safety, environmental sustainability by LCA, life cycle costing and social readiness level are assessed in each iteration.

The first LCA iteration of the ViSS assesses all impact categories recommended by the Product Environ-

mental Footprint (PEF) guidelines with cradle to gate system boundary with the focus on materials. The study identifies environmental impact hotspots in early stage of the production design and compares these environmental impacts with those of benchmark state-of-the-art plastics, thereby validating the progressive sustainability of the plastics in the market.

Characterizing circularity, climate and energy benefit of plastic recycling options using carbon flow and circular diagrams

Chengyao Zhang, Jun Nakatani

Department of Urban Engineering, The University of Tokyo, Japan

Plastic recycling offers critical opportunities for achieving a circular economy, particularly as a sustainable source of carbon for chemical and plastic products. Commonly, evaluations of recycling/recovery technologies have focused on carbon neutrality, especially for the reduction of climate change impacts through decreased greenhouse gas (GHG) emissions and resource conservation in fossil energy. Recently, however, the concept of carbon circularity, which emphasizes retaining carbon within the economy system, has gained prominence. Despite its growing importance, there is no framework to simultaneously explore the circularity, climate, and energy aspects of the recycling/recovery options. To bridge this gap, we propose carbon flow and circular diagram (CFCD) method, providing a unified framework to evaluate recycling systems by integrating carbon circularity, carbon neutrality, and independence from fossil energy. The CFCD method visualizes carbon flows, mapping inputs (e.g., plastic waste, fossil fuels) and outputs (e.g., recycled products, recovered energy, CO2 emissions) across recycling/recovery pathways. Using this framework, the carbon circularity rate, can be calculated by quantifying the proportion of carbon retained in recycled products relative to input waste. Additionally, climate and energy benefits can be quantified based on the input and output in the recycling and substitute systems. The framework is applied to recycling/recovery options including mechanical recycling, chemical recycling, and energy recovery systems. Mechanical recycling achieves moderate carbon circularity alongside a maximum GHG emission reduction of 0.37 kg CO2 eq/kg waste, while high-efficient energy recovery systems (e.g., cement burning) deliver climate benefits but lack circularity. Catalytic cracking balances these aspects but remains energy-intensive. Notably, gasification for ammonia production demonstrates most energy savings but lacks in carbon circularity, therefore, the potential to improve circularity with carbon capture and utilization was proposed. Characterization of recycling/recovery options using CFCD method can contribute to multifaceted yet consistent discussion on the improvement in circularity, climate and energy benefits.

Assessment of sustainability benefits using comparative LCA of recycled PET and virgin PET with a case study of fibers.

Karishma Sameer Tijoriwala, Harsha Reddy, Soumen Munshi, Anand Sharma, Pattaraporn Khamhongsa, Vishwesh Pavnaskar, Samrat Bose

Indorama Ventures PCL

PET is one of the most durable and cost-effective polymers used to produce consumer packaging and textiles. While being fully recyclable only a fraction of the post-consumer PET is given a second life. Improving this can help meet the growing demand of low carbon and durable clothing while mitigating PET waste.

IVL is actively recycling post-consumer PET since 2011, with a target of recycling 1.5 million tons annually by 2030. The recycled PET (rPET) is used to produce packaging grade plastic and fibers. An LCA study was conducted to compare the cradle to gate impact of fibers using virgin PET produced on site from fossil-based feedstock with recycled PET processed from waste PET bottles. In this case, the cut-off approach is applied to rPET. The study was conducted in accordance with ISO 14040/44 following reporting guidelines

outlined by WBCSD and TfS.

Our findings reveal that the impacts of rPET fibers for most midpoint indicators is significantly lower compared to vPET fibers. GWP 100 years is reduced by 45%, while a 100% and 68% reduction in abiotic elemental and fossil depletion respectively is observed. The savings are due to major difference in raw materials. Energy requirements are lower for rPET fibers by 48% due to lower requirement of thermal energy which is predominantly produced from coal. The freshwater consumption is higher for rPET fibers for cradle to gate. To mitigate the this, the site works actively to recycle water.

The quality and durability of fabric produced with rPET is at par with vPET and has the potential of replacing vPET in the textile industry with conscious consumption of water.

The study highlights, that recycling is not just a way to combat plastic waste, but also to lower the carbon footprint of textile products along with providing socio-economic benefits for local communities.

Life Cycle Assessment of a toy demonstrator, manufactured by recycled plastic toy waste

Despoina Antypa[1], Anastasia Gkika[1], Foteini Petrakli[1], Raquel Berbegal[2], Ana Ibáñez[2], Asunción Martínez[2], Elias P. Koumoulos[1]

[1]IRES, Belgium; [2]AIJU, Spain

The toy industry is considered to be the most plastic-intensive industry in the world, while plastic toys burden the environment at the life cycle stages of both their production and disposal. In fact, it is estimated that huge amounts of toys in the EU turn to waste annually, with their vast majority going to landfill or incineration. So, toy waste may unlock an enormous potential of plastic recycling, along with the environmental benefits of less plastic waste as well as of less virgin plastic production. At the same time, initiatives deriving from the European Plastics Strategy boost the use of recyclates in plastic everyday products. The current research adds to this target, as it examined at environmental level a plastic toy-boat demonstrator that is manufactured by 100% recycled plastic from post-consumer toy waste. To do so, Life Cycle Assessment (LCA) was performed for the toy-boat, to assess its potential environmental impacts at a life cycle perspective, to identify any environmental hotspots and unlock possible mitigation actions for climate change. Specifically, post-consumer discarded toy waste was recycled at pilot level, with the rich in polypropylene (PP) fraction used as material input for the toy-boat production. The manufacturing process included compounding and injection molding, while part of the manufacturing waste has the potential to be directly recycled in closed loop. Apart from the LCA results that facilitate decision making towards sustainability, this research targeted to enable meaningful comparisons between recycled plastic and virgin plastic products, highlighting the environmental benefits deriving from the avoidance of virgin plastic production.

Advancing Plastics Disaggregation in Multi-Regional Input-Output Databases

Maddalen Ayala Cerezo[1], Albert Osei-Owusu[2], Maik Budzinski[2], Mathieu Delpierre[1], Philip L. Coenen[1], Jannick Schmidt[1,2]

[1]2-0 LCA consultants, Denmark; [2]Aalborg University, Denmark

Plastics play a critical role in modern life; however, environmentally extended multi-regional input-output (MRIO) databases, such as the hybrid EXIOBASE, currently aggregate all plastics into one product and industry category, limiting its ability to support detailed assessments of plastics. This research, conducted as part of the Getting the Data Right project, contributes to the enhancement of hybrid EXIOBASE and the development of the BONSAI climate footprint calculator, a unique open-source tool based on the hybrid EXIOBASE framework. Sector modules are introduced to improve the database's resolution for plastics, enabling

better analysis of their production pathways, environmental impacts, and potential for circularity.

Sector modules are Python packages implementing algorithms that perform the tasks for the different products derived from disaggregating existing products. The methodology analyses regional production data, applying key coefficients, namely emission factors and feedstock requirements, to estimate emissions, resource use, and material flows specific to plastic types. Data sources include industry reports, statistical databases, and scientific literature to construct parameter tables reflecting regional variations in plastic production. These tables contain data on production volumes, input coefficients, carbon and waste intensities, with related uncertainty information, and account for the dynamics of the plastic value chain, including mass and carbon balance validations to ensure data accuracy.

By improving the resolution of global MRIO tables within the BONSAI framework, the results provide region-specific production recipes and carbon footprints for a robust environmental analysis and decision support. A detailed report documents the methodology and findings, ensuring transparency and facilitating the use of these data in advancing sustainable and circular plastic solutions.

By adopting an open-source approach, this research enhances the accessibility and reliability of the updated database. It addresses critical gaps in understanding plastic production processes and their environmental implications, providing valuable insights to advance environmental and economic research on plastics.

Session 2.22: Filling the Gaps in Life Cycle Assessments of Upstream Materials for the Sustainable Deployment of Battery Ecosystems

Time: Thursday, 11/Sept/2025: 4:30pm - 6:00pm
Session Chair: Sophia Roy, Polytechnique Montréal, Canada
Session Chair: Luka Smajila, KTH - Royal Institute of Technology, Sweden

A framework for prospective life cycle assessment of upstream material supply chains

Sophia Roy[1], Ketan Vaidya[2], Louis Fradette[1]

[1]Polytechnique Montréal, Canada; [2]Northvolt AB, Sweden

Available inventories for upstream materials suffer from many layers of aggregation, preventing life cycle analysts to easily pinpoint key impact contributors. In turn, identified contributors are the foundation of prospective assessments allowing to measure potential improvements in environmental impacts.

We propose a technology-agnostic framework to conduct prospective life cycle assessment on upstream raw material supply chains of any product, in the present case critical minerals for a battery cell.

1) The present work starts at the reconstruction of raw material life cycle inventories via disaggregation of processing routes, current and/or emerging.

2) The use of process-based granular inventories streamlines the identification of emerging technology switches that could mitigate key contributors to environmental impacts.

3) Simplified process models are constructed for selected emerging technology switches.

4) A technology adoption period for technology switches is determined from their TRL, informed by a literature review, or expert consultations.

5) Process-based granular inventories are parametrized for progressive evaluation of time-dependent technology switches;

6) Environmental impact contributions of each technology switch are calculated in comparison to status quo.

To illustrate our framework, we provide a proof-of-concept with battery-grade nickel. Our process-based reconstruction demonstrates variability in impacts as high as 130 kgCO2eq/kg Ni equivalent. Our prospective evaluation of key contributors showcases a potential reduction in carbon footprint between ~40% and 75% depending on the nickel processing route. Furthermore, based on a 17 midpoints assessment, we address mitigation measures to prevent burden shifting.

Our prospective evaluation method prevents over-optimistic modelling while allowing to pinpoint and quantify benefits from key technological improvements in material supply chains. We anticipate the validation of our method with other raw materials, such as lithium and iron phosphate.

Reducing environmental impacts and material footprint of Li-ion battery production for electric vehicles and their recycling: a cradle-to-cradle life cycle analysis and circularity assessment

Jordy Motte[1], Laura Vittoria De Luca Pena[1], Ligia Da Silva Lima[1], Michael Hofmann[2], Ksenia Astafyeva[3], Kawther Thabet[3], Razieh Sarani[2], Constantin Hübner[4], Stefan Eisert[4], Uwe Guntow[2], Jo Dewulf[1]

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The EU mobility strategy aims to boost the major shift from combustion powered vehicles to electric vehicles by 2030. Li-ion batteries, such as LiNiCoMnO2, play an important role in this shift as these are often chosen in electric cars because of their excellent performance in terms of energy density, cycle stability and lifetime. Nevertheless, their production causes substantial environmental impacts (e.g., greenhouse gas emissions) and results in a significant demand for critical raw materials such as lithium, cobalt, etc. In the RecyLib project, a solventless melt process is used to produce LiFePO4 and LiNiCoMnO2 cathodes for Li-ion batteries. This alternative production method can potentially decrease the environmental impacts for the cathode and Li-ion battery production because no solvent is required for manufacturing and it allows remanufacturing of used electrode material. Moreover, this innovative process can reduce the energy need for its production. Direct recycling of the Li-ion batteries is also investigated in this project to close the loop for the required critical raw materials. This work aims to assess the environmental impacts of Li-ion battery production via the RecyLib process, the subsequent recycling and the remanufacturing of the batteries with the recycled materials (cradle-to-cradle life cycle assessment (LCA)). Primary data at lab scale was obtained from the partners in the RecyLib project. These data were scaled up to allow for a fair comparison with commercial Li-ion battery production. For the impact assessment, relevant LCA indicators were considered based on guidelines for the metal and mining sector. Moreover, a circularity assessment was conducted to quantify how circular this production system is compared to commercial Li-ion battery production and recycling methods. For this assessment, relevant indicators (e.g., material circularity indicator from Ellen McCarthur Foundation) were identified and selected. Future research can focus on a comprehensive life cycle sustainability assessment, alongside criticality aspects.

Using LCA in technology development – the case of structural battery cell technology

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A novel technology developed at Chalmers University of Technology is lithium-ion structural battery cells. Structural battery technology combines the capacity for carrying mechanical loads with energy storage in composite structures for use in e.g. mobility applications. This contribution reports on life cycle assessment (LCA) work that has been done to provide decision-support for technology development at early stages (TRL 3). Important starting points have been prospective LCA, suitable for assessing emerging technologies, and stakeholder engagement. This contribution describes the developed approach, while demonstrating the utility of a participatory approach for LCA, despite challenges in data gaps at early stages and the issue of increased complexity with handling the multifunctional dimension of this technology.

A life cycle inventory was first developed for the lab-scale situation by means of observations, and interviews with the developers of lithium-ion structural cell. Results, discussed in participatory workshops, highlighted environmental hot-spots and improvement opportunities in upstream materials, direct energy use in processing steps and waste management. The significance of including energy consumption for structu-

ral battery cell testing and conditioning was identified.

The participatory workshops with material and technology developers also informed the prospective LCA, that looked into future scenarios for technology generations and structural battery cell production. Additional data were collected to align with technology planning. Scenarios envisioning scaling-up of the production to full-scale manufacturing were modelled. Scenarios for future background electricity data for Sweden were explored. Supporting production alternatives for the technology, such as additive manufacturing processing was evaluated. A trade-off was found between wastage reduction and direct energy use in processing.

Finally, placing the structural battery cell in the context of a vehicle application proved challenging due to the multifunctional dimension of the technology which requires new vehicle designs for more detailed evaluations and makes direct comparisons to existing technologies impossible.

Life Cycle Assessment of a battery Container Storage System based on Sodium-ion and Lithium-ion Batteries

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The shift towards renewable energies, coupled with their inherent intermittency has led to a growing need for energy storage capacity in stationary applications. In order to drive the energy transition in a sustainable manner, a thorough assessment of the environmental impact of storage technologies is essential. However, particularly for Container Storage Systems (CSS), which play a central role in this context, there is a notable lack of detailed life cycle inventory (LCI) models of such systems, as most studies do not include all Balance of System (BOS) components, such as the thermal management system, power electronics or the housing with insulation.

To fill this research gap, this work presents a streamline LCA of a new generic LCI model of a CSS, thus enabling comparable sustainability assessments in the future. The model is based on commercially available CSS and includes all BOS components. It enables scientists to model their battery cells into it and thus investigate the environmental impact in a stationary context. In this study, the system is investigated with the most widely used and promising battery cell chemistries for stationary applications Prussian Blue Analogues (PBA, a sodium-ion battery) and Lithium-Iron Phosphate (LFP, a lithium-ion battery). In addition to the assessment of the production phase, the use phase is examined with different use cases for stationary applications and results are presented per kWh energy delivered. This study therefore enhances the understanding of the current environmental impact of CSS and identifies key areas for improvement, providing valuable insights for future advancements.

Filling the gaps by the development of a life cycle inventory database for electromobility battery recycling processes and recycled materials

Emilie Guilvert, **Noura Rahbani**, **Perrine Sebastien**, **Naeem Adibi**

WeLOOP, France

In 2018, transport accounted for 30% of Europe's greenhouse gas emissions. To achieve decarbonization, the EU has prioritized electric mobility, with plans to ban the sale of new internal combustion engine vehicles by 2035. Global electric vehicle (EV) sales surpassed 10 million in 2023; a 55% increase from 2022. However, this rapid EV adoption has significantly increased the demand for lithium-ion batteries, which rely on critical and strategic materials such as lithium, cobalt, and nickel that present environmental challenges, particularly at their end-of-life. Recycling plays a crucial role in recovering valuable resources, reducing im-

port dependence, and mitigating disposal risks.

The EU Regulation 2023/1542 addresses these challenges by mandating carbon footprint reporting for EVs starting 2025 and requiring detailed documentation of recycled content in EV batteries by 2028. However, current life cycle assessment databases lack adequate data on recycling processes and materials, hindering comprehensive assessments.

In this context, WeLOOP is developing an extensive database of battery recycling processes, including pyrometallurgy, hydrometallurgy, and direct recycling. Drawing on collaborative projects with industrial partners, including recyclers, the database comprises over 500 datasets covering various regions, with both aggregated and disaggregated data. This database is expected to grow as technological advancements in battery recycling emerge. The database is also designed to integrate additional battery technologies and innovative recycling processes that align with the Carbon Footprint Formula.

WeLOOP's parametrized datasets can be tailored to meet the specific needs of users. For instance, stakeholders can access customized data on recycled metal salts based on unique black mass compositions and geographic conditions.

This database aims to help industry stakeholders comply with regulations, improve environmental impact assessments and support research into sustainable battery technologies and innovative recycling methods. Through this project, WeLOOP intends to promote the implementation of a circular economy for batteries in Europe.

Enhancing battery LCA data: addressing critical gaps and enabling consistent analyses

Antonio Valente, Iasonas Ioannou, Valeria Superti, Lauriane Bichot, Thomas Sonderegger

ecoinvent, Switzerland

Over recent decades, background data has been essential in supporting sustainability assessments globally. These assessments are highly data-intensive, relying on inventory data for processes, materials, and energy flows. The ecoinvent database, with extensive data coverage across various sectors, has become a valuable resource for LCA practitioners. However, the partial availability of secondary, and lack of primary, data for batteries production poses challenges to LCA studies. This, in turn, could become problematic in assessing large-scale deployment of renewable energy systems, electric vehicles, and energy storage, which are rapidly growing due to the green transition. Besides, upcoming policies and regulations mandate substantiating environmental profiles (e.g., carbon footprints) through LCA, highlighting the need for more consistent and accurate data on battery technologies. Addressing this requires strategic efforts to (1) identify critical LCI data gaps, (2) facilitate effective communication and collaboration between data providers, industry, and policymakers and (3) develop and supply high-quality, consistent, and granular data across various battery chemistries.

We begin by establishing the need for enhancing the availability of LCI data for batteries for which data gaps are identified. This includes, but is not limited to, key components and compounds used in active materials, electrolytes, salts, solvents, additives, and precursors used in cells. We continue by showcasing how ecoinvent data teams, spanning areas from chemicals and plastics to metals and batteries, are addressing these challenges by (1) reviewing existing literature on battery LCA, (2) incorporating user and expert feedback to identify and prioritize key areas for improvement, and (3) collaborating to enhance data availability. Building on the identified bottlenecks, we finally explore how primary and secondary data can aid in mitigating the risk of inconsistent results and support policy frameworks for battery assessments that increasingly rely on LCA.

Prospective Life Cycle Assessment of Emerging Battery Technologies and Recycling Pathways

Daniel Habermeier, Levin Winzinger, Abhishek Khairnar, Dr. Denise Ott

EurA AG, Germany

The transition to renewable energy systems depends on innovative battery chemistries that offer improved performance, enhanced sustainability, and reduced reliance on scarce materials. While lithium-ion batteries dominate the market, their dependence on limited resources such as lithium, cobalt, and nickel raises concerns about resource scarcity, environmental impacts, and geopolitical risks. Addressing these challenges requires a dual approach: developing post-lithium battery technologies using abundant materials and adopting efficient recycling processes to close material loops and reduce raw material demand.

This study investigates the environmental performance of lithium-ion battery (LIB) recycling approaches, as well as the production and recycling of emerging zinc-air, zinc-manganese, and calcium-sulfur battery systems, which utilize more abundant and widely available materials. Additionally, it explores the methodological complexities involved in assessing these up-coming technologies, including data gaps, scalability issues, and the integration of recycling processes.

A key challenge in the life cycle assessment of emerging battery technologies is the comparison with well-established systems (LIBs), which benefit from industrial-scale production and extensive optimization. Emerging chemistries, typically assessed at laboratory scale, face data limitations requiring assumptions about material and energy consumption, recycling processes, and functional performance, which introduce uncertainties. Assumptions about recycling are essential but often speculative for both LIBs and novel chemistries. Standardized assumptions, such as those from the EU Battery Regulation, may oversimplify real-world dynamics but provide a pathway to harmonize methodologies, enabling consistent evaluations across technologies.

By employing a structured framework of assumptions, this study assesses the environmental potential of LIB recycling and emerging battery technologies, highlighting their capacity to address resource scarcity, environmental impacts, and geopolitical risks.

This work was supported by the German Federal Ministry of Education and Research (BMBF) as part of the ZinCycle (03XP0493F), ZiMaBat (03XP0481F) and CaSino (03XP0487B) projects and by the European Union in EU-Horizon Project BeyondBattRec (GA-ID-101193032).

Life Cycle Assessment of Li-ion Batteries (LIBs) for Battery Electric Vehicles (BEVs): From Production through Usage to Recycling

Inyoung Ko, Wonjae Choi

Ewha Womans University, Republic of Korea

Battery Electric Vehicles (BEVs) have garnered significant attention as environmentally friendly means to reduce greenhouse gas emissions in the transportation sector. However, lithium-ion batteries (LIBs) emit significant greenhouse gas (GHG) emissions during production, usage, and disposal processes. Life cycle assessment of LIBs have primarily focused on the production process, whereas research on the impacts of LIB usage and recycling processes remains insufficient. To address this research gap, this study quantifies the GHG emissions throughout the entire life cycle of LIBs, from raw material extraction, refining, production, and actual usage to recycling. Additionally, this study compares and analyzes different types of batteries, such as NMC, LFP, and NCA. The GREET2 and EverBatt models were utilized to analyze GHG emissions during the battery production and recycling processes. The degradation process of LIBs was simulated by using the GT-SUITE and Autolion program during analyzing usage stage. The reduction in capacity and charging-discharging efficiency induced by degradation is investigated. The fuel efficiency of vehicles, which varies depending on the type of battery, was also considered. Consequently, it becomes

possible to compare the greenhouse gas emissions during the battery charging process, reflecting degradation characteristics, as well as the emissions associated with different recycling methods. This allows for a more accurate understanding of the sustainability of LIBs and BEVs. Moreover, it provides valuable information for decision-making processes by pinpointing the stages in the LIB life cycle that contribute most significantly to GHG emissions, thereby aiding the development of effective emission reduction strategies.

Integrated Framework for Electric Vehicle Battery Sustainability: Combining Life Cycle Assessment and Circular Economy

Anna Sánchez, Gabriela Benveniste, Isabella Bulfaro, Mikel Fadul, Víctor José Ferreira

FUNDACIO INSTITUT RECERCA ENERGIA CATALUNYA (IREC), Spain

Electric vehicles (EVs) powered by lithium-ion (Li-ion) batteries drive the transition toward sustainable road transport, offering an alternative to conventional combustion engine vehicles. However, batteries can contribute approximately 40% to 60% of an EV's total carbon footprint over its life cycle. Beyond carbon emissions, battery production impacts other environmental categories such as water usage, toxicity, and mineral resource depletion, underscoring the need for comprehensive evaluation methods.

LCA is a well-established standardised tool for assessing environmental impacts, while Circular Economy (CE) is an emerging framework that emphasises resource recovery and material recirculation. These methodologies are usually applied separately. While numerous studies have assessed the environmental impacts of Li-ion batteries through LCA, these often lack insights into the recirculation potential of materials - except within the cradle-to-cradle (C2C) approach. Conversely, CE strategies frequently overlook detailed environmental impacts, leading to incomplete assessments of sustainability performance unless that is integrated with LCA. Despite their complementarity, the combined application of LCA and CE methodologies remains limited and warrants further exploration.

The IntelLiGent project addresses this gap by applying LCA and CE indicators outlined in the ISO/FDIS standard 59020 within an integrated framework. This approach will evaluate Li-ion batteries' environmental impact and material recovery, providing a comprehensive sustainability assessment. Furthermore, it also examines the alignment of LCA, the new EU Batteries Regulation and ISO/FDIS standard 59020. This work refines LCA-CE integration by developing standardised circularity metrics and expanding applications to various battery chemistries, harmonising sustainability and circularity goals, ensuring compliance, supporting decisions, and fostering innovation in the battery sector. Preliminary findings show that the Life Cycle Inventory from the LCA provides around 65% of the required data for applying circularity indicators, and four sustainability requirements from the Batteries Regulation align with circularity indicators. This study has been carried out with the EU-funded Project IntelLiGent, GA101069765.

Session 2.23: LCA & Natural Capital: Driving Nature-Positive Outcomes

Time: Thursday, 11/Sept/2025: 4:30pm - 6:00pm
Session Chair: Alexandra Evans, Vito, Belgium
Session Chair: Sun-Hea Hong, University of Stuttgart, Germany

Midpoint characterization model for water consumption impacts on aquatic ecosystem: RESCUE model

Masaharu Motoshita[1], Kamrul Islam[1], Markus Berger[2], Anne-Marie Boulay[3], Amandine Pastor[4], Stephan Pfister[5], Georg Seitfudem[3], Francesca Verones[6], Matthias Finkbeiner[7]

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The impacts of water consumption through life cycle of products/services/organizations have been the subject of considerable. AWARE model has been widely used for the assessment of the impacts of water consumption as a generic midpoint indicator, while demand for ecosystem-specific characterization models for water consumption has been increasing with the growth of request and interest on sustainable management of ecosystems along with the international initiatives, e.g. IPBES, Taskforce on Nature-related Financial Disclosures, and Nature Positive Initiative. In response to this demand, we have developed a new midpoint characterization model for assessing the impacts of water consumption on aquatic ecosystems: RESCUE model. The developed ecosystem specific model has some similarity with AWARE model in the modeling concept, while it specifically captures the potential impacts on aquatic ecosystems. First, environmental water requirement for aquatic ecosystem is defined based on the flow regimes in a watershed, and then, overconsumption of water by human activities is determined to assess the extent of deprivation of water for aquatic ecosystem as a potential impact on ecosystems. We have developed characterization factors for around 11,000 watersheds covering the whole globe which can be also aggregated into country scale. As a result, 80% of the global watersheds where we consume water already face the deprivation of water for aquatic ecosystem. The extent of deprivation reaches at 60% of water for aquatic ecosystem requirement. In this presentation, we present the details of the model and results, and highlight the similarity and differences between RESCUE and AWARE model.

From LCA to Environmental Value Creation – The GUH Standard as a Tool for Natural Capital Management & Value Chain Empowerment

Jan Koepper, Anne L.G. Lange

Gemeinsam umweltneutral handeln e.V., Germany

Founded in 2024, the GUH association strives towards its purpose of rendering visible the environment's value(s) as well as making sustainable actions competitive. Its key instrument is a standard for environmental value creation to enable a holistic approach to natural capital management and renaturation. Embedded in the prevalent discourse on sustainability, the standard seeks to innovate current approaches to sustainability management, challenge respective approaches via a multi-capital-based approach to sustainability strategies and ultimately serve economic and societal needs and, as a corollary, promote socio-economic and socio-cultural developments.

The standard is scientifically reviewed and based on LCAs for products, organisations and public authorities/municipalities. It aims to systematically internalize external effects by monetizing environmental impacts throughout the life cycle. LCA results are used to form reduction strategies, translate impacts into

environmental costs and develop concrete corresponding measures for environmental value creation that strengthen eco-system regeneration. Each standard step involves clear guidance and quality measures to ensure alignment with the principles of inclusiveness, reliability, replicability, quality and innovative capacity.

Users of the standard include a variety of SMEs and municipalities that have tested and actively integrated the approach for certain products, services and processes. Within the framework of these principles, the GUH develops and establishes target group-specific formats that aim to make sustainable behaviour attractive to society. The label, reflecting the standard conformity, seeks to contribute to consumer empowerment, increased value chain transparency and supply chain management. In line with regulatory developments and with a specific focus on supporting resilience, renaturation and eco-system thrive-ability, the standard provides a sound and innovative instrument for natural capital management and sustainable development.

We are grateful to present the details of the standard, conflicts of interests and challenges articulated by its users, the overall vision as a blueprint for multi-capital-based approaches to transformation and societal value creation.

Streamlining Life Cycle Assessment and Natural Capital Accounting: Identifying Synergies and Challenges for Enhanced Sustainability Evaluation

Rafael Horn[1,3], Alexandra Evans[2], Andreas Gess[3], Marina Sarralde[5], Daniel Whitaker[4], Sharon Stauffert[3], Sun-Hea Hong[3]

[1]Fraunhofer IBP, Germany; [2]VITO; [3]University of Stuttgart; [4]IDEEA Group; [5]Tecnalia

Assessing the impact of products and organisations on nature has become a key requirement, especially in the context of European Sustainability Reporting Standards (ESRS) and sustainability disclosure obligations. At a product level, environmental impacts are well captured through LCA, which is agnostic to sectors and environmental areas of protection, focusing on completeness and comparability of life cycle impacts. At a corporate level different approaches are available focusing on specific applications and environmental realms. Natural capital accounting (NCA) is an approach tailored to quantifying natural capital in terms of stocks (e.g. ecosystems, water bodies) and flows (e.g. ecosystem services, flows of water). While both LCA and NCA frameworks are harmonized and accepted, they are oftentimes applied separately causing both inconsistencies and unnecessary double work. A harmonized application requires the specification of interlinkages, synergies, and potential barriers to allow streamlined integration in decision making and accounting.

We will provide a systematic investigation of LCA and NCA aiming to identify and create synergies through joint or complementary application. Therefore, both are analysed focusing on key terminology, system understanding including implicit preconditions, explicit boundary conditions and modelling requirements as well as main tools, applications, and result structure. The underlying data structures will be investigated in a parallel submission.

Key findings will be investigated focusing on barriers and opportunities for a joint underlying harmonized assessment framework as well as mutual improvement potentials for both LCA and NCA. Key challenges addressed will involve key assumptions and simplifications, value chain consideration, spatial resolution, temporal resolution, modelling principles as well as generic and specific model requirements. We will provide recommendations on dealing with inconsistencies and provide a practical example to demonstrate the potential of joint application.

NCA, LCA and spatial data – developing a harmonized data structure for corporate reporting on nature

Alexandra Evans[1], Bruno Smets[1], Karolien Peeters[1], Catarina Braga[2], Daniel Whitaker[3], Jacob Bedford[2], Rafael Horn[4]

[1]VITO; [2]UNEP-WCMC; [3]IDEEA Group; [4]Fraunhofer IBP

With the recent adoption of the EU Corporate Sustainability Reporting Directive (CSRD), companies will be required to report on their environmental and social impacts according to the European Sustainability Reporting Standards (ESRS). The need to meet the requirements of reporting directives has resulted in the development of a plethora of databases and tools, but a holistic method to manage nature data, calculate indices and report impacts to comply with the CSRD remains lacking. Natural Capital Accounting (NCA) and Life Cycle Analysis (LCA) are both recommended in the ESRS for quantifying impacts and dependencies on biodiversity and ecosystems. The alignment of the ESRS with the System of Environmental Economic Accounting (SEEA) in its framing of topics in terms of extent and condition of ecosystems presents clear opportunities for the use of NCA and spatially-explicit data, but the potential for the use of such structured data with LCA methods remains unclear. As part of the Horizon Europe project A-TRACK, we are investigating the potential of using public remote sensing data structured following the principles of the SEEA Ecosystem Accounting to calculate nature impact metrics, and how this data structure can be complementary to LCA in corporate sustainability reporting. In particular, we demonstrate how structured public data can be informative in the analysis of parts of a product value chain with spatial resource- and land-use impacts, and how data structured in accordance with NCA principles has the potential to improve the specificity and relevance of characterisation factors for impacts on biodiversity. We use an example case from the sector to delve into the practical challenges and opportunities associated with structuring public spatial data and the limitations of its use in tandem with LCA for sustainability reporting.

Integrating biodiversity and ecosystem service footprints into LCA: leveraging insights from natural capital accounting

Sun-Hea Hong[1], Marina Isasa Sarralde[2], Sharon Stauffert[1], Andreas Gess[1], Rafael Horn[3]

[1]University of Stuttgart IABP, Germany; [2]Technalia Research and Innovation, Spain; [3]Fraunhofer IBP, Germany

In the contemporary business environment, there is an increasing demand to measure and report their impacts on nature as stakeholders seek more data-driven insights about environmental risks and opportunities. This necessitates aligning business efforts with public natural capital accounting (NCA) and ecosystem services to track the private sector's contribution to sustainability targets. Whilst LCA, and particularly the Environmental Footprint (EF 3.1) method recommended by the European Commission, is particularly suited for a harmonised environmental assessment along value chains, there is currently no unified approach to quantifying ecosystems services and related impacts and dependencies within this framework.

By addressing the current gaps in ecosystem services quantification, this framework not only aids companies in meeting regulatory requirements but also empowers them to align their sustainability goals with economic growth. It suggests ways to integrate EF 3.1 with established Natural Capital Accounting (NCA) principles and to operate across geo-spatial scales (national, regional, local). It aims to include a suite of models to cover Ecosystem Services, including not only provisioning but also regulation and maintenance, and biodiversity impacts. It is proposed to be adaptable based on data readiness, the maturity level of practitioners, reporting purposes, and the types of decision-making involved.

The framework handles large-scale assessments with limited information for screening while also allowing for comprehensive evaluations utilizing site-specific collected data and parameterised calculations with full precision. The proposed background data structure and principles are aligned with the current land use impact category in EF 3.1 LANCA® as well as the biodiversity impact method BioMAPS.

The framework supports alignment with emerging regulatory requirements and the criteria and recommen-

dations of the Global Reporting Initiative (GRI), Corporate Sustainability Reporting Directive (CSRD), and Taskforce on Nature-related Financial Disclosures (TNFD), among others. Additionally, the framework addresses "assessing" and "disclose" within the ACT-D framework from business for nature coalition.

Science and Finance: Evaluating Biodiversity Metrics for Financing in Europe

Marina Dumont[1], An De Schryver[1], Imene Ben Rejeb-Mzah[2], Alexandre Vincent[2]

[1]PRe Sustainability, The Netherlands; [2]BNP Paribas, Paris, France

Human activities have severely impacted the environment, with biodiversity loss from ecosystem collapse posing an imminent threat. The destruction and artificialization of habitats alone account for 30% of biodiversity impacts, with forests being particularly affected—420 million hectares lost in the past 30 years. Recognizing its role, the global finance sector seeks to improve practices to put less pressure on biodiversity and therefore necessitating robust methodologies to measure biodiversity impacts of financed activities.

This case study, conducted with BNP Paribas, analyses two biodiversity metrics—Potentially Disappeared Fraction of species (PDF) from ReCiPe 2016 and Mean Species Abundance (MSA) from GLOBIO3.5 - used for estimating biodiversity impacts across financial portfolios. PDF estimates species loss due to anthropogenic activities, focusing on the amount of different species groups, i.e. species richness, while MSA measures the abundance of species relative to a pristine baseline, capturing declines within and across species groups. Each metric and model have advantages in estimating biodiversity impacts of financial activities. ReCiPe 2016 covers more impact categories to ecosystem damage than GLOBIO3.5 currently does. Conversely, MSA is more sensitive in capturing changes to biodiversity than PDF.

The effectiveness of these metrics and thus biodiversity impact calculations also depend on the background databases used to assess the financial portfolios. When assessing financial portfolios, given their size and diversity, this is often done on sectoral level using input-output databases. However, using process databases and a more detailed modelling approach will improve decision-making relevance but demand significant time and effort.

This presentation will present three primary challenges currently encountered when assessing the biodiversity impact of financial portfolios and reflect upon how those three challenges could be bridged, between state-of-the-art biodiversity metrics and the financial world, to drive practical, scientifically-sound, and most importantly, actionable insights for the financial market.

Assessing the Spaciotemporal Degradation of Cameroon's Mangroves: Drivers, Consequences and Mitigation: Case of Bekumou, Bakassi Peninsular for Test of Methodology

Godlove Ambe Neba, Barry Achi Ashu, Gracious Remyeh Kifon, Neculina Anyinkeng

University of Buea, Cameroon

Mangrove forests are one of the most productive ecosystems in the world, playing crucial roles in maintaining coastal biodiversity, providing ecosystem services, and supporting livelihoods. Globally, they are the most threatened tropical ecosystem, being degraded and depleted at alarming rates. Mangroves in Cameroon cover about 2000 km2, grouped into 3 main blocks, with over 20% in the Rio de Rey Estuary. The island of Bekumu, Bakassi Peninsula is one of the oldest fishing ports in Cameroon, with an ever-increasing population that depends on mangrove for construction, and fish smoking, their only economic activity. Acute mangrove degradation has let to severe consequences, including tidal inundations and high wave activity, property loss and thousands displaced in 2024. The methodology developed, assess the level of environmental degradation, drivers, risks, perceptions of environmental change and willingness to contribu-

te towards rehabilitation. Imagery techniques; ground truthing; shoreline observation; field measurements and socioeconomic surveys were used. Intact mangrove coverage and terrestrial forest regressed by 29.2% and 10.3% respectively, while degraded mangrove, agricultural land and settlement space increased by 26.6%, 10.5% and 2.5% in that order within a 30 years span. Satellite imagery indicated a inland shoreline movement of about 20 m while respondents who have leaved in the area for over 70yrs said wave action have moved the shoreline over 100m inland. Unregulated collection of construction material, fuelwood and climate change were key drivers observed while Sea level rise and encroachment, high wave action and reduced fish catch were highly cited consequences. Respondents acknowledged their role in environmental degradation, already implementing local policy of "non-motorised" harvesting and transportation of mangrove wood, sand bag barriers against high waves and expressed willingness to participate in alleviation projects. This paper discusses how the findings could inform methodological advancements in Life Cycle Sustainability assessments related to mangroves in specific contexts

Session 2.24: LCSA for decision making in energy systems

Time: Thursday, 11/Sept/2025: 4:30pm - 6:00pm
Session Chair: Maurizio Cellura, Università di Palermo, Italy
Session Chair: Olubukola Olumuyiwa Tokede, Deakin University, Australia, Australia

Biomethane Splitting: Unveiling the Regulatory Barriers to Biohydrogen and Carbon Removal Potential

Isabella Bulfaro[1], Anna Sánchez[1], Mikel Fadul[1], Gabriela Benveniste[1], Beatriz Amante[2], Víctor Ferreira[1]

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While hard-to-abate CO_2 intensive sectors such as steel, cement and heavy transport need sustainable hydrogen for decarbonisation, the development of the hydrogen market remains hindered by significant barriers, including distribution, high production costs, and regulatory uncertainty. Methane and biomethane splitting directly cracks methane into hydrogen and added-value carbon, avoiding direct CO_2 emissions.

This study conducts a greenhouse gas (GHG) emissions assessment of the biomethane splitting process, applying the different methodologies defined in the EU Renewable Energy Directive (RED III) and UK Low Carbon Hydrogen Standard regulations, and Life Cycle Assessment (LCA) hydrogen guidelines. Each methodology explores different approaches for biogenic CO_2, carbon sequestration credits, and multifunctionality accounting.

The UK Low Carbon Hydrogen Standard assigns carbon credits to solid carbon when it is incorporated into concrete and cement or kept in inert underground storage, while biogenic CO_2 is accounted for as 0. In this case study, GHG emissions are equal to -7.4 kg CO_2eq/kgH_2. In contrast, the EU RED III does not include carbon credits, and biogenic CO_2 is excluded from the calculation, resulting in emissions of 2.1 kg CO_2eq/kgH2. Moving to LCA, including biogenic CO_2, the GHG emission increases to 5.3 kgCO_2eq/kgH_2 when generic biomethane is applied, to -1.16 kgCO_2eq/kgH2 adopting wood biomethane origin.

The Red III framework does not distinguish between different uses of carbon, which hinders the recognition of the carbon removal potential associated with biomethane splitting. Conversely, when applying LCA including biogenic CO_2, higher overall emissions are observed when biomethane derived from biowaste is used, thereby potentially discouraging circular economy practices. Among the regulatory frameworks, the UK regulation appears as the best option for the biomethane splitting GHG emission accounting, avoiding potential double counting and recognising the technology's carbon removal potential when carbon is stored or embedded in permanently bound products.

Advancing Sustainable Aviation Fuel: The Process of Including Non-Standard Coconut in ICAO's Positive List

Marvin Pinggala Danadipa Lieus[1], David Adiwijaya[1], Jessica Hanafi[1], Suyoto Rais[2]

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The aviation industry is under increasing pressure to decarbonize and transition to sustainable energy sources. Sustainable Aviation Fuel (SAF) has emerged as a key solution, with significant potential to reduce greenhouse gas emissions compared to conventional jet fuel. However, including feedstocks in the International Civil Aviation Organization's (ICAO) Positive List remains a challenge, especially for unconventional feedstocks such as non-standard coconut.

This paper examines the process of incorporating non-standard coconut as a viable SAF feedstock in

ICAO's Positive List. The lack of a clear definition for non-standard coconut required extensive stakeholder engagement and survey development to establish credibility. A comprehensive definition was proposed, supported by documentation showing that non-standard coconut naturally occurs during aggregated harvesting practices, ensuring its sustainability and addressing food loss by utilizing coconuts that would otherwise be discarded.

Key preparatory activities included consultations with Japan's Civil Aviation Bureau, Indonesia's Ministry of Agriculture, the International Coconut Community, and ICAO's Fuel Task Group. Surveys and site visits across Sumatra and Sulawesi engaged eight stakeholders, including farmers, collectors, and factories. These surveys collected critical inventory data and assessed sustainability risks following the Roundtable on Sustainable Biomaterials (RSB)'s 12 principles. Translating these principles into practical and accessible terms posed significant challenges, necessitating adaptations to ensure meaningful engagement with farmers and local stakeholders. This iterative process underscored the importance of balancing scientific rigor with practical applicability in data collection efforts.

In addition to these efforts, Life Cycle Assessment (LCA) evaluated the environmental performance of non-standard coconut as a SAF feedstock. The study aligns with ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) and highlights the potential for rural economic development, enhanced supply chain resilience, and reduced reliance on conventional feedstocks. This replicable framework supports aviation's decarbonization goals and contributes to broader climate targets.

Thermochemical methanation of biogas: a sustainability assessment

Giampiero Sacchi[1], Daniele Ferrario[1], Alessandro Agostini[2], Jacopo Bindi[2], Claudio Carbone[2], Alberto Giaconia[2], Claudia Bassano[2], Roberta Roberto[2], Andrea Lanzini[1]

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This work focuses on an innovative thermochemical pathway, demonstrated within the BIOMETHAVERSE project, to enhance biomethane productivity and quality. Unlike conventional methods that separate CH4 and CO2 in biogas using membranes or scrubbing techniques, this process consists of the methanation of the CO2 contained in the biogas with green hydrogen following the well-known Sabatier reaction. This approach allows for increased production of biomethane, the reuse of waste CO2, which will be otherwise emitted into the atmosphere, and the storage of renewable hydrogen within the biomethane stream, achieving a CH4 purity of 95%, suitable for gas grid injection.

While technological advancements are required for improving synthetic biomethane production and quality, and reducing production costs, it is equally essential to assess the broader environmental and social implications of its production.

Our study emphasizes the importance of a comprehensive Life Cycle Assessment (LCA) to evaluate the environmental and social impacts of this novel process. The environmental LCA assesses greenhouse gas emissions, environmental impacts, and resource efficiency, while the social LCA examines social repercussions along the supply chain. The results are compared to current biomethane production methods to highlight potential improvements in sustainability and societal benefits.

Additionally, a Techno-Economic Analysis is conducted to assess the financial viability and production costs. By integrating social and environmental LCA with economic analysis, this study provides a holistic evaluation of the proposed technology and its possible role in the ecological transition of the energy sector.

This work is funded by the EU Horizon Europe Project BIOMETHAVERSE: Demonstrating and Connecting Production Innovations in the BIOMETHAne uniVERSE.

Grant agreement ID: 101084200

Integrating Energy Systems Modelling and Life Cycle Sustainability Assessment: A framework for greener, fair and balanced energy transitions

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Energy transitions are complex processes that require institutions to make informed, science-based decisions to achieve sustainability objectives. While countries like Spain have made significant progress in integrating renewable energies, decision-making frameworks have predominantly prioritised economic and environmental dimensions, often neglecting potential social impacts of energy systems. Social Life Cycle Assessment (S-LCA) has gained increasing recognition as a robust methodology to evaluate social impacts across value chains of (energy) systems. However, existing energy systems modelling frameworks lack integration of social life cycle indicators into energy planning, creating a gap in holistic sustainability assessment of energy transitions. This work proposes a novel methodological framework that, for the first time, combines energy system optimisation with Environmental Life Cycle Assessment, Life Cycle Costing, and S-LCA. The framework enables the design, evaluation and prioritisation of energy scenarios that balance economic, environmental, and social criteria. By integrating indicators such as carbon footprint, costs, and risks of social concerns like child labour into energy system models, this approach ensures the development of energy pathways aligned with sustainability policies, governance, and regulations.

The framework has been applied to a case study on the Spanish electricity mix projected towards 2050 using a LEAP-based energy system optimisation model. Preliminary results highlight that, under a business-as-usual scenario, social impacts are not aligned with decarbonisation goals. Specifically, risks such as child labour could be maintained or worsened in the long term. This underscores the need to integrate social sustainability criteria alongside environmental and economic indicators into energy planning to prevent undesirable outcomes in energy transitions. This innovative framework provides decision-makers with essential insights to evaluate trade-offs, prioritise scenarios, and promote energy transitions that are greener, balanced, and socially inclusive. By addressing all three pillars of sustainability, the framework aligns with evolving policy frameworks and supports decision-making in industry and governance.

Integrating Predictive Models into Prospective LCAs of Biochar Application to Soil

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Biochar application to soil (BAS) represents a promising strategy for carbon dioxide removal (CDR) and sustainable agriculture. However, the effects of environmental variables on the CDR efficiency are understudied, and the effects of the CDR on the environment too (Prütz et al. 2024). To create a robust framework and holistically assess BAS across diverse environmental and agricultural contexts, our work integrates outputs from two predictive modeling approaches into the prospective Life Cycle Assessment (pLCA) of BAS.

The first approach employs a mechanistic biochar-to-soil model (Archontoulis et al. 2016). This model has been expanded in this work to accommodate diverse locations, climate conditions, and biochar feedstocks. The second approach is an original machine learning (ML) framework. Using a Random Forest algorithm trained on data from over 800 field trials, the ML model predicts key outcomes such as crop yield, pH, soil

organic carbon and nitrogen dynamics.

In addition to these predictive tools, this research integrates outputs and scenarios from Integrated Assessment Models (IAMs) using PREMISE (Sacchi et al. 2022) to ensure alignment with broader CDR-focused strategies. IAM scenarios provide boundary conditions and input data for the pLCA framework, while the pLCA outcomes feed back into IAMs to refine and validate CDR-focused scenarios, ensuring bidirectional utility.

Rather than solely evaluating these methodologies, this research integrates their outputs into prospective and regionalized LCAs to comprehensively analyze BAS's co-benefits and trade-offs. The combined approach leverages the mechanistic model's granularity alongside the ML model's versatility to create a robust framework for assessing BAS across diverse environmental and agricultural contexts.

This work advances LCA methodology by integrating advanced, reusable, and open-access predictive tools, providing innovative pathways to evaluate and optimize biochar use on a global scale. The findings deliver actionable insights to promote sustainable practices, supporting broader goals of climate change mitigation and soil health enhancement.

Session 3.01: Handprints as a method to accelerate the sustainable Transition

Time: Friday, 12/Sept/2025: 9:35am - 11:05am
Session Chair: Gregory A. Norris, MIT, United States of America
Session Chair: Sonia Valdivia, WRFA, Switzerland

Assessing Scope 1, 2, 3 and 4 Biodiversity and Climate Change Impacts of Investments

Stephan Pfister[1], Shuntian Wang[1], Viktoras Kulionis[2]

[1]ETH Zurich, Switzerland; [2]Pictet Asset Management, Switzerland

Inconsistencies in defining and quantifying the net environmental impacts of business activities hinder the comparability and reliability of sustainability assessments across organizations. In this presentation we introduce a generalized and operational methodology for calculating net impacts of businesses for informing investments. We addressed greenhouse gas (GHG) emissions, and stressors for biodiversity loss, building on the frameworks proposed by Kander et al. (2015), Russell (2019), and Kulionis et al. (2024). The methodology integrates advanced multi-regional input-output (MRIO) databases with life cycle inventory data from ecoinvent. In previous work, we analysed biodiversity impact of the MSCI All Country World Index (MSCI ACWI) with ~3000 large- and mid-sized companies from 23 developed and 24 emerging countries. As the main biodiversity impacts are caused in the Americas and Asia although these regions have a low representation in the index's country weight (6%) (Kulionis et al. (2024), we also focused on regionalized aspects and international trade.

While the developed approach is operational, some major challenges remain:

First, defining of reference products or activities in for scope 4 emissions is crucial for the outcome and therefore critical concerning greenwashing efforts. Sensitivity analyses show that the choice of reference product within a sector can have huge impacts on the net impact results of activities.

Second, the hybridization of MRIO and LCA data to resolve aggregation limitations, is limited by the limited sectoral resolution of MRIO as well as the limited business coverage and spatial resolution in LCI. We assessed the sensitivity to the trade data using different GMRIO databases.

We conclude that the framework for net impact quantification using a hybrid MRIO-LCA approach enables impact assessment in the finance industry. However, sensitivity analyses demonstrate that the results need to be carefully interpreted.

References:

Kander et al. (2015) https://doi.org/10.1038/nclimate2555

Kulionis et al. (2024) https://doi.org/10.1111/jiec.13515

Russell (2019) https://www.wri.org/insights/many-companies-inaccurately-estimate-climate-benefits-their-products

Balancing Footprint and Handprint in the Coatings Industry

Pau Huguet Ferran, Ioannis Voulgarakis, Anna Valgeirsdottir

Hempel

Sustainability leadership necessitates both excellent corporate responsibility and ability to meet customer needs. This dual approach involves managing both the environmental footprint and handprint simultaneously. The environmental footprint is addressed through the traditional Scope 1-2-3 framework, while the handprint focuses on maximizing the sustainability value of products to avoid downstream impacts and provide significant benefits to end users.

In practice, comprehensive all-round solutions that effectively balance both footprint and handprint are rare. Organizations often struggle to align these aspects to achieve their sustainability goals and speed industry transition at the same time. Moreover, without a compelling handprint case, companies face significant challenges in commercializing their sustainable solutions to drive their own sustainability performance.

The coatings industry exemplifies this dilemma. Paints and coatings are crucial for society and sustainability, playing a vital role in enhancing circularity and decarbonizing various sectors. They protect buildings, infrastructure, and other assets from corrosion, reduce maintenance needs, and improve energy efficiency. However, coatings are part of a hard-to-abate sector that requires a strong market pull to drive its own decarbonization.

The footprint of coatings has a minimal impact on downstream activities, and there are limited upstream incentives to develop and use raw materials with lower emissions. This paradox makes the implementation of sustainability at scale in the coating industry difficult.

This presentation will compare two case studies from a global leader in the coatings industry. One where footprint and handprint are synergistically aligned, distributing sustainability value across the value chain and driving commercial success, and another involving a commoditized product with a less attractive handprint, limiting opportunities for footprint improvement. We will discuss the main barriers and opportunities in commercializing sustainable products and fostering sustainable transition, and reflect on the trade-offs and strategies that companies and society must address to drive transformation.

Driving Sustainability- The Role of LCA in Carbon Reduction: The case of AMG lithium in electric vehicles application

Marcella Volta[1], Katie Livesey[1], Peter Shonfield[1], Henry Shere[1], Hugh Whetherly[1], George Parthmer[2], John Hunt[2], Joe Leonard[2]

[1]ERM; [2]AMG

Businesses are facing increasing pressure from consumers and stakeholders regarding the environmental impact of their products. At the same time, greenhouse gas emissions (GHG) continue to rise, and various policies worldwide are aimed at promoting sustainable production practices to mitigate climate impacts. The EU regulation is indeed progressing toward CO2 reduction, facilitating activities central to the EU Taxonomy Initiative.

AMG critical Materials N.V. (AMG) is a global critical materials company founded on the trend toward CO2 abatement, which simultaneously creates additional demand for materials classified as “critical” by the European Commission. This means that AMG’s goal is to enable customers to reduce carbon emissions through enhanced energy efficiency. To achieve this, AMG has developed a methodology to measure the energy savings enabled by its products, refined by linking it to the Life Cycle Assessment (LCA) methodology in collaboration with ERM. This approach provides carbon reduction data for each qualifying AMG product.

Over the past few years, ERM and AMG have collaborated to assess LCAs for an expanding portfolio of products, creating a virtual portfolio that enables carbon reduction. This portfolio includes, among others,

several types of alloys, graphite, ferrovanadium, and a lithium-vanadium (LIVA) battery.

This paper highlights the potential of using Life Cycle Assessment (LCA) to illustrate the impact of AMG products and their associated benefits. In particular, the presentation focuses on the avoided emissions linked to lithium applications in electric vehicles compared to internal combustion engines across different markets.

Enhancing Urban Climate Strategies through Handprint Actions: A Focus on the Transportation Sector

Laura Lakanen[1], Petri Kero[2], Juho Vento[1], Pinla Nokkanen[2], Kaisa Grönman[1], Olli Helppi[1], Mikko Ropo[1], Risto Soukka[1]

[1]LUT University, Finland; [2]The City of Lappeenranta, Fnland

The role of cities in mitigating climate change is crucial. Despite extensive efforts to reduce their carbon footprints, cities face the challenge of costly residual emissions, which eventually need to be compensated when aiming at net zero. This study explores the potential of handprint actions as a complementary approach to traditional footprint reduction methods, aiming to achieve significant and cost-effective emission reductions.

Handprint actions refer to measures that reduce the carbon footprints of other actors compared to baseline situation, thereby creating a potential positive climate impact. By systematically mapping these actions and enhancing the city's handprint potential, urban climate efforts can be significantly bolstered. This research focuses on the transportation sector, identified as a major source of urban emissions, and assesses the handprint potential of various measures using the handprint framework. As an essential step, residual emissions are also mapped to assess their magnitude and the costs associated with their reduction or compensation.

Our findings indicate that a sector-specific systematic approach, utilizing the handprint framework and calculations, can be highly beneficial in municipal climate work. Preliminary results suggest that integrating handprint actions with traditional footprint reduction strategies can lead to more effective and comprehensive climate change mitigation. In the transportation sector, handprint actions can include, for example, building new charging infrastructure, adding shared electric vehicles, or developing new tax credit models to encourage the adoption of low-carbon mobility options. In addition to minimizing their own footprints, cities should explore other emission reduction opportunities and allocate funds also for handprint actions. This approach may enable a more cost-efficient way to reduce emissions compared to focusing solely on reduction and compensation of costly residual emissions. By adopting this dual approach, cities can accelerate the achievement of climate goals both locally and globally.

Exploring Handprint Potential: A Forward-Looking Measure for Positive Climate Impact

Mikko Juhani Ropo, Olli Juhani Helppi, Laura Maria Lakanen, Risto Matias Soukka

LUT University, Finland

Carbon handprints are increasingly recognized for their multifaceted benefits in both product and organizational contexts. On a product level, handprints signify the assistance provided to customers in reducing their carbon footprints, highlight positive impacts of purchases, facilitate strategic planning, and enable a goal-oriented approach to creating positive impacts. On an organizational level, handprints demonstrate the climate benefits of aiding others, promote business opportunities through climate solutions, broaden the

scope of climate action, and support the achievement of global net zero targets.

While methodologies exist for calculating carbon handprints at the point of realization, or close to it, these methods are not complete for predicting positive impacts of a solution in earlier phases of its development. Developing methods for assessing handprint potential is essential to enable actors to implement strategies that reduce emissions both within and outside their value chains, thereby maximizing their contribution to climate change mitigation.

This research aims to elucidate the concept of handprint potential, its evaluation process and its significance in guiding product development towards achieving substantial positive climate impacts. The application of handprint potentials is demonstrated through case examples in different stages of product development and strategic planning in companies.

Handprint potential was found to be a suitable metric for predicting the positive climate impacts of future solutions. Evaluating the handprint potential of a solution can begin at the conception of an idea and continue through market research, product development, marketing strategy, product launch, and ultimately, the customer's purchase decision. Handprint potential can guide product development, although the uncertainty of evaluation is higher in the earlier phases and decreases as the product approaches the purchase decision stage. Ability to evaluate handprint potential is vital in describing opportunities that are yet to be realized or challenging to evaluate using existing methods.

How to showcase environmental impact mitigation through innovation? An application of the environmental handprint approach to wastewater treatment technologies

Silvia Forin[1], Katri Behm[1], Tiago Furlanetto[2], Mona Arnold[1]

[1]VTT; [2]APCL

Demonstrating the environmental impacts of products should follow a transparent methodology to prevent both greenwashing and greenhushing in sustainability communication.

The "Carbon Handprint Guide v.2.0 - Applicable for Environmental Handprint*" outlines an approach for these assessments. Its framework includes more than just measuring footprint reduction, as it defines a handprint as "the beneficial environmental impacts that organisations can achieve and communicate by offering products and services that reduce the footprints of others".

Prior to the typical LCA scoping phase, the handprint method requires setting the handprint scope, i.e., identifying the function of the offered solution, the potential handprint contributors, the environmental impacts/benefits, the beneficiaries of the offered solutions and the baseline scenario. The resulting handprint is calculated as the difference between the impact of the baseline solution and the impact of the proposed solution.

This contribution examines the use of the environmental handprint method for assessing innovative technologies in tertiary wastewater treatment, including a sample calculation. The handprint is characterized as a reduction in specified emissions (such as Al, Cd, Pb) identified before implementing the technology, with the company operating the wastewater treatment plant as the beneficiary. A comparison with the baseline (the state prior to adopting the new solution) demonstrates how the technology's impact on sustainable transitions can be quantified.

*Pajula, T., Vatanen, S. and Behn K. (2021): Carbon handprint guide v.2.0. https://publications.vtt.fi/julkaisut/muut/2021/Carbon_handprint_guide_2021.pdf

Leveraging Handprints to Accelerate Adoption of Sustainability Principles in Engineering Education and Quantify their Positive Contributions

Jasmina Burek[1], Kiara Winans[2], Alana Griggs[1], Nelson Granda-Marulanda[3], Greg Norris[4]

[1]University of Massachusetts Lowell, United States of America; [2]Virginia Tech, United States of America; [3]North Carolina Agricultural and Technical State University; [4]Massachusetts Institute of Technology, United States of America

Highlighting sustainability in engineering education aligns with the growing need to prepare future engineers for global challenges. Universities are updating curricula, expanding courses on sustainability, and emphasizing impactful research. Many engineering programs fail to fully prepare students to work within sustainability frameworks, often addressing only a few grand challenges and lacking integration of real-life projects or active learning. There is a critical need to accelerate the broader adoption of sustainability principles in engineering education and to create opportunities for students to make meaningful, positive, and measurable contributions to sustainability efforts throughout their studies.

The University Handprint Framework (UHPF) uniquely addresses this gap by offering an approach to accelerate adoption of sustainability principles and standardize measurement of university-led sustainability initiatives, focusing on their collaborative impacts with external organizations. We propose adoption of an innovative concept "handprints", which implies a proactive, positive contribution to sustainability, as opposed to the traditional "footprints" which often focus on negative impacts.

MIT Sustainability Lab's course, in which students engaged in project-based learning to address real-world sustainability challenges of organizations, serves as a case study showcasing the UHPF's potential. This partnership resulted in a substantial reduction of ~740,000 kg CO2e per year, demonstrating the potential of academic partnerships to drive environmental change. Our ongoing research tests the scalability of UHPF across diverse institutions, including Virginia Tech, North Carolina Agricultural and Technical State University, and the University of Massachusetts Lowell. By refining the UHPF, we aim to provide a standardized method adaptable to various institutional contexts, fostering innovation and collaboration and empowering future engineers across all disciplines to address pressing global challenges.

This presentation will introduce UHPF and its potential to catalyze change in engineering education. This research provides a practical example how academic institutions can employ UHPF and transform education practices to accelerate the sustainable transition.

10:53am - 10:59am Warning: The presentations finish prior to the end of the session!

Integrating Beyond Value Chain Mitigation into the Core of Corporate Climate Action

Olli Juhani Helppi, Mikko Ropo, Laura Lakanen

LUT university, Finland

Despite the ability of companies to affect climate impacts beyond their value chain, corporate climate action guidance predominantly focuses on carbon footprint reductions within the corporate value chain. Value chain mitigation (VCM) means reducing emissions in the scopes 1,2 and 3 of the company. Beyond value chain mitigation (BVCM) refers to emissions reductions outside these scopes. To holistically understand the climate impacts of a company, it is essential to consider not only its carbon footprint, but also how its actions enable carbon footprint reductions elsewhere. By regarding carbon footprint reductions as the primary course of climate action for all organizations, we risk deflating the emergence of climate change mitigation from companies whose strengths lie in initiating reductions outside their own carbon footprint.

BVCM is usually considered voluntary work that organizations can pursue in addition to VCM. We propose that both VCM and BVCM should be viewed as pathways of organizational climate contribution. Instead of prioritizing VCM by default, companies should pursue either VCM or BVCM based on where their action can contribute best to climate change mitigation. Which pathway provides the best impacts depends on multi-

ple variables, such as the company's business model, available resources and level of political advocacy.

We reflect VCM and BVCM to a case study in plastics recycling. Based on our findings we provide guidelines for efficient climate action to support decision-making of organizational actors. We discuss the sources of uncertainty in BVCM approaches and whether to prioritize VCM or BVCM. Our results support the global pursuit of net-zero emissions by helping organizations to direct their resources towards actions that provide the highest return on investment in terms of climate change mitigation.

Session 3.02: LCT based Tool for Sustainability in Industry

Time: Friday, 12/Sept/2025: 9:35am - 11:05am
Session Chair: Stephan Krinke, Fraunhofer IST, Germany
Session Chair: Juan Felipe Cerdas Marin, Technical University of Applied Sciences Würzburg-Schweinfurt, Germany

Advancements in LCA-based biodiversity footprinting for use in CSRD/ESRS E4

Colette Grosscurt, Shaniq Pillay, Rudri Mankad

PRe Sustainability, The Netherlands

The Corporate Sustainability Reporting Directive (CSRD) requires companies to assess the actual and potential impact on biodiversity and ecosystems of their own operations and up- and downstream value chain. In the past years, many companies have conducted a biodiversity footprint at portfolio-, company-, and supply chain-levels. Thus going beyond regular product-level Life Cycle Assessment (LCA) and thereby advancing methodological development, data requirements and application of LCA at a different scale as required for corporate reporting. This presentation will zoom in on two main advancements based on case studies.

Financial institutions can nowadays screen thousands of companies for biodiversity footprint hotspots at sector x country-level and use that to calculate biodiversity footprints of specific companies. This helps meet reporting requirements of ESRS E4 Biodiversity and Ecosystems. Firstly, it allows to identify and address potential biodiversity risks or opportunities across the value chain as required for materiality assessment (ESRS 2 IRO-1). Secondly, it informs potential engagement programs with companies to mitigate biodiversity loss, which feeds into action plans (E4-3). Thirdly, it feeds into policy definition on biodiversity (E4-2).

Another advancement is assessing the potential avoided impact of biodiversity by impact investors. They invest with explicit criteria for sustainable interventions to improve biodiversity impacts. Currently, LCA datasets are limited in the extent to which they cover more sustainable practices. Methodologies and data have been developed to capture and better reflect e.g. mandatory certification principles for sustainable agricultural practices. This allows for meeting CSRD requirement on positive impact on biodiversity and measuring progress. Additionally it informs the development towards a commonly accepted definition.

Finally, ongoing applications of biodiversity footprinting provide insights in challenges of scaling up LCA for use in the CSRD. Such as data gaps, key drivers of biodiversity loss like invasive species, local representation of datasets and CFs and metric interpretation.

Sustainable Innovation or Merely Reporting? State of the Art of Assessing Carbon Emissions from Organizational Procurement

Widiene Essouid[1,2], Johannes Zobel[3], Philippe Loubet[1], Sandra Köhler[3], Stéphane Trébucq[2], Andrea Thorenz[3], Axel Tuma[4], Guido Sonnemann[1]

[1]Institute of Molecular Sciences, University of Bordeaux; [2]Research Institute for the Management of Organizations, University of Bordeaux; [3]Resource Lab, University of Augsburg, Germany; [4]Chair of Production & Supply Chain Management, University of Augsburg

Amid increasing efforts and regulatory pressure towards carbon accounting practices for organizations, the suitability of commonly applied methods is questioned. Procurement, in particular, can significantly contribute to an organization's total emissions, yet their accurate assessment remains challenging. Currently, employed assessments are either based on Life Cycle Assessment (LCA) using activity or process-based data or Environmentally Extended Input-Output (EEIO) using spend-based data. While basic reporting and voluntary carbon offsets can be conducted on the basis of rough calculations, the necessary transformation to sustainable innovations and subsequent decarbonization must be based on reliable and accurate data to identify evidence-based reduction opportunities. Through a systematic literature review, this study explores the current state of practices for assessing procurement emissions, identifies key methodological challenges, and evaluates the suitability of commonly used methods for supporting a sustainable transition on an organizational scale. Results reveal that 40 % of all selected case studies employ either a spend-based EEIO approach or a hybrid approach combining LCA and EEIO. While LCA offers the accuracy needed for actual decarbonization, challenges such as data availability and methodological complexity persist. EEIO reduces truncation errors when allocating in LCA and is less complex to implement but fails to offer the necessary granularity required to reduce environmental impacts and track progress. Hybrid approaches offer a balanced compromise enabling comprehensive procurement emission assessments within data, time, and resource constraints. An analysis of the examined case studies shows that while concrete decarbonization targets are predominantly set, most rely on imprecise spend-based or aggregated data, hindering effective decarbonization. This contribution invites discussions on advancing and harmonizing procurement emission assessments to reach beyond mere reporting or compensating, thereby enabling reliable and impactful sustainability strategies.

Environmental and Economic Evaluation of Low-TRL Technologies for Soil and Water Bioremediation

Patricio Iván Cano, Germán Cavero

Blue Synergy, Spain

Human activities introduce contaminants into the environment (soil, water, and air), causing significant problems due to their persistence and toxic effects on all living organisms. Consequently, these contaminants must be removed, a process that incurs costs and requires environmentally responsible methods. In this context, remediation using natural-based systems (NBSs) is emerging as an attractive solution. However, these technologies are still at a low technology readiness level (TRL). Nonetheless, the most promising ones are expected to be adopted in the coming years.

Life Cycle Assessment (LCA) and Life Cycle Costing should be applied to these technologies to identify hotspots and validate their environmental and economic benefits, including biodiversity protection. In this regard, conducting LCAs and LCCs can support decision-making by integrating current technological knowledge with environmental impacts and costs to explore the feasibility of future applications. In brief, well-founded decisions from LCA/LCC results ensure optimal outcomes for both remediation and ecosystem health.

Previous studies have highlighted the challenges of performing both LCA and LCC at low TRL, with data limitations and uncertainty identified as the primary factors to address during execution. To overcome the-

se challenges, the current work has focused on defining the proper goal and scope based on an analysis of system boundaries, frameworks, and assumptions. Likewise, the following natural-based systems (NBSs) have been evaluated from an environmental and economic point of view: i) phytoremediation assisted by microorganisms for soil remediation, ii) phytoremediation assisted by microorganisms for contaminated estuarine restoration, iii) wastewater and polluted groundwater restoration using bioelectrochemical systems (BES), iv) combining phytoremediation with BES treatment for simultaneous soil and water remediation, and v) wastewater purification using biostimulation treatments. Low yields in phytoremediation scenarios and the use of metals in BES technologies have been identified as two limiting factors for NBS from a sustainability perspective.

Increasing SMEs' Accessibility to ISO-Compliant Reporting: The Role of Automation and Standardisation in Lowering Costs

Lucille Wagner[1], **Leo Breedveld**[2]

[1]*Lifecycles, Australia;* [2]*2B, Italy*

Small and medium-sized enterprises (SMEs) encounter distinct challenges in estimating and reducing their environmental impacts while effectively communicating their initiatives. Often lacking in-house expertise for life cycle assessments (LCAs), they rely on costly environmental consultancies. The scrutiny of environmental claims raises concerns about greenwashing accusations, leading companies to pursue ISO compliance for credibility. However, the stringent ISO requirements involve lengthy processes and significant resource commitments, discouraging many SMEs from pursuing environmental initiatives. Those that do participate may underreport their efforts - known as "greenhushing" - which limits public awareness and reduces opportunities for leadership in sustainability.

The prohibitive cost of ISO compliance arises from the highly manual processes involved in conducting and reviewing comparative LCAs, resulting in lengthy reports that lack a predefined structure, despite many studies sharing similar aims and background data sources. To alleviate the burden of report writing and critical review, standardisation of ISO 14044 requirements can be implemented for specific product comparisons.

The Packaging Impact Quick Evaluation Tool (PIQET) addresses these issues by providing a standardised methodology for assessing and comparing packaging. It guides users in defining project scope and motivations, selecting indicators, and assessing data quality. By standardising key methodological decisions and offering results interpretation through standardised contribution assessments and sensitivity analyses, PIQET automates the generation of peer-reviewable, ISO-compliant LCA reports.

Our aim was to create a user-friendly, streamlined tool that empowers SMEs in the packaging sector to tackle environmental challenges and confidently communicate their positive initiatives while ensuring transparency and peer reviewability for ISO compliance. This presentation will discuss the design considerations and challenges faced in achieving a balance between simplicity and thoroughness in the latest tool update.

How Schneider Electric +20 years of operational experience in Life Cycle Management is helping to address the mandatory reporting tsumani

Benjamin Canaguier, Sebastien Dufour, Manel Sansa, Adina Braha-Honciuc, William Lepercq

Schneider Electric, France

Over the last couple of years, private companies have seen an exponential increase of reporting standards and format with more scrutiny from regulators, investors and customers. European Green Taxonomy and CSRD are 2 major ones that forces the corporate sphere to step up their reporting capabilities. To report upon the Green Taxonomy and to prepare the first reporting exercise of the CSRD, Schneider Electric has relied on two decades of operational experiences in implementing Life Cycle Management in its operations. Publishing +2000 Product Environmental Profile (PEP) over the past 15 years and implementing Ecodesign for about 10 years systematically into its new offer development has strongly support Schneider Electric management to prioritize reporting, support decision making in the materiality assessment, communicate on third party verified environmental impact and support the identification of the do not significantly harm criteria. In order to report CSRD for the first year, Schneider Electric type III PEP were used to disclose scope 3 downstream emissions and drive decarbonization roadmap across business units. Additional resources inflows (weights, recycled content, secondary materials) and resources outflows (durability, recyclability) mandatory quantitative requirements from ESRS E5 also rely on Life Cycle Assessment information. Schneider Electric aims at continuing in relying on robust scientific and third party verified information to strengthen its reporting practicing while harmonizing them across the industry

Exploring the Application of Life Cycle Costing in Chemical Processes: A Comparison with Techno-Economic Analysis

Yuree Kwon[1,2], Jinjoo An[1]

[1]Korea Research Institute of Chemical Technology, Korea, Republic of (South Korea); [2]Department of Environmental Engineering, Chungnam National University, Daejeon, Republic of (South Korea)

Transitioning to a circular economy and adopting sustainable procurement practices require comprehensive consideration of the environmental, social, and economic impacts across the entire life cycle of products and services. Consequently, life cycle assessment and life cycle costing have become important tools for evaluating long-term environmental and economic impacts. This trend has gained increasing attention in the chemical process. In this field, life cycle assessment and techno-economic analysis are commonly utilized to assess the environmental and economic viability of introducing production technologies or projects for target chemical products. Techno-economic analysis plays a significant role in evaluating the feasibility of specific technologies by considering initial investment and operational costs. However, it often falls short of evaluating the long-term economic value of products from a sustainability perspective. In contrast, life cycle costing offers a comprehensive economic evaluation by considering costs across the entire life cycle of a product, including production, use and disposal. This holistic approach can significantly contribute to advancing toward the sustainable society demanded by the international community. Despite its potential, the application of life cycle costing remains limited in the chemical process industry. This study explores whether life cycle costing should be considered instead of techno-economic analysis in the chemical process industry, with a focus on assessing the feasibility of sustainable procurement beyond short-term profitability. This study employs a case study approach to evaluate the economic performance of basic chemical products using both techno-economic analysis and life cycle costing. By comparing the results of these analyses, the necessity of adopting life cycle costing in the chemical process industry is discussed.

Attitudes towards EU taxonomy among sea-related industries' stakeholders

Cristina-Maria Iordan, Andrea Viken Strand, Thea Luras Oftebro

SINTEF OCEAN, Norway

The European Union (EU) has set a goal to achieve climate neutrality by 2050, necessitating specific measures and strategies. One key tool in this effort is the EU taxonomy, a classification system designed to establish a common definition of sustainable economic activities. This paper seeks to explore the potential impact of the EU taxonomy on Norway's maritime industries.

The research relies combines LCA studies, literature review and interviews with stakeholders from cruise ship industry, vessel yards, battery production and paint manufacturing.

Session 3.03: LCM for an enhanced circularity in steel and other metals

Time: Friday, 12/Sept/2025: 9:35am - 11:05am
Session Chair: Luiz Kulay, University of São Paulo, Brazil
Session Chair: Diego C Magalhaes, ArcelorMittal, Brazil

Recalibrating the European Aluminium and Steel sector towards a Circular Economy Transition

Paola Federica Albizzati[1], Anna M. Walker[1], Aymara Wagner[1,2], Leonidas Milios[1], Pablo Piñero Mira[1], Malte Besler[1,3], Luis Pedauga[1], Davide Tonini[1]

[1]Joint Research Centre - European Commission, Spain; [2]Institute of Environmental Sciences, Leiden University, Netherlands; [3]Fraunhofer ISI, Karlsruhe, Germany

The transition to a Circular Economy (CE) is considered as the cornerstone for achieving the objectives of the EU Green Deal. However, EU policies to improve material circularity and more sustainable supply chains remain limited. Hence, a recalibration of the existing CE policies is required to accelerate this transition. In this context, we present the results of the Joint Research Centre exploratory project "RecalibrateCE", which aims at developing a framework to assess the performance of the European economy in its transition to a circular one. It provides guidance on the creation of effective CE policy instruments for the supply chain of aluminium and steel, two carbon-intensive metals with high potential of closing the material loop and of strategic importance to the competitiveness of the European single market. The research comprises an integrated assessment, including material flow analysis, bottom-up life cycle assessment and costing, environmentally extended input-output analysis, and macroeconomic modelling. The two industry sectors are analysed from an environmental and socioeconomic perspective to identify bottlenecks that prevent the transition to more circular systems. In the assessment, the baseline scenario is compared against an advanced circular economy scenario, where a range of possible CE interventions are considered. These interventions address the reduction of virgin material inputs (e.g., optimised production), reusing of parts and products (e.g., extension of product lifetime), and increased recycling (e.g., improved sorting). The analysis of the baseline scenario highlighted key issues, namely the importance of energy mixes, the limited high quality and closed-loop recycling, and the export of scrap. The potential of addressing these issues through implementing more ambitious CE interventions at EU level is assessed to promote CE as the main model of sustainability in these two key industrial sectors.

Environmental impact assessment of the laser micro-cladding manufacturing process for the energy sector

Rocio Pena Rois, Leandro A. Rodriguez-Ortiz, Carlos Bernardez, Félix Ares-Blanco, Nerea Otero, Alexandre Cunha

AIMEN, Spain

Environmental sustainability plays a crucial role in the development of innovative manufacturing processes, as industries strive to reduce environmental impacts and improve resource efficiency. One emerging technology under investigation is micro-cladding (µCLAD), a process that utilizes the melting and solidification of metal powder to repair, manufacture, and functionalize high-value-added parts. This clean, resource-efficient technique has broad applications across various industries, including die and tool making, turbine and engine components for aeronautics, and power generation.

Despite its numerous advantages, µCLAD lacks comprehensive environmental assessments for many of

its applications. To address this gap, this study applies a rigorous LCA approach to evaluate the environmental impacts of laser-based manufacturing processes at the laboratory scale. The research focuses on using µCLAD to create complex 3D surfaces in turbines that mimic natural textures. They are designed to reduce friction and enhance energy efficiency and performance during the use phase, thereby contributing to sustainability goals.

The results highlight that electricity consumption is the most significant contributor to environmental impacts, accounting for an average of 45% of the total. Argon consumption follows, with a contribution of 35%, while steel consumption has the lowest impact, averaging 20%. The most affected impact categories are climate change and ecotoxicity. These findings emphasize the importance of targeting energy efficiency and material consumption in process optimizations to minimize environmental footprints. Although the energy impact of the process is high, it is expected to be compensated by the higher efficiency achieved during the use phase.

This work is part of the European Project BILASURF (Grant Number: 101091623), which aims to advance sustainable laser-based manufacturing technologies. The results provide valuable insights for the adoption and improvement of µCLAD in industrial applications, reinforcing its potential as a sustainable alternative in high-value manufacturing sectors.

Life Cycle Allocation Strategies for Recycling Zinc from Galvanized Steel: Advancing Circularity in the Multi-Metal Industry

Hemant Sharma, Sabina Grund

International Zinc Association, Germany

Zinc plays a critical role in enhancing the durability of steel, with approximately 60% of global zinc production used for galvanization to prevent corrosion. At the end of its service life, galvanized steel is recycled in electric arc furnaces (EAF), where zinc evaporates, re-oxidizes, and forms EAF dust—a hazardous by-product. To advance circularity in the steel and metals industry, this dust is processed to concentrate zinc into Waelz oxide, a valuable material that substitutes mined zinc ore. The traditional cut-off allocation approach in Life Cycle Assessment (LCA) penalized the use of recycled zinc. Since the current EAF dust enrichment process is carbon intensive, resulting in a higher carbon footprint for recycled zinc compared to its mined counterpart.

In response, the steel and zinc industries have adopted system expansion methodology, which allocates recycling burdens to steel production while crediting the replacement of primary zinc ore. This research elaborates this approach along with other allocation methodologies for zinc recycling that align with three key principles: (1) compliance with relevant standards, (2) encouragement of zinc use with higher recycled content, and (3) prevention of double counting in the interconnected, multi-functional metal industry. Additionally, this study highlights vulnerabilities in current LCA methodologies, such as Product Environmental Footprint (PEF), to double counting due to the interconnected nature of the multi-metal recycling industry.

Impact of adding granulated blast furnace slag on the carbon footprint of Portland cement: a study conducted in Brazil.

Thalya Fortuna Vieira[1], Rudiele Aparecida Schankoski[1], Luiz Alexandre Kulay[2]

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Portland cement is widely used in the construction industry, but its production has significant environmental impacts, particularly its carbon footprint. Recent data from the Brazilian Portland Cement Association indicates that the cement industry is responsible for 7% of global emissions related to human activities contributing to Global Warming. The sector seeks ways to improve the situation by recognizing the challenges posed by this adverse environmental profile and its potential effects on future business transactions. One possible approach is modifying cement composition by replacing conventional raw materials with by-products from other processes with a lower carbon footprint. However, there is still limited quantitative information in the literature regarding the true impact of these substitutions on emission reductions. This study aims to address this gap by comparing the carbon footprints of two types of Portland cement: one made with Granulated Blast Furnace Slag (GBFS), classified as CP III according to ASTM C595 Type IS, and high early strength Portland cement without slag, classified as CP V by ASTM C150 Type III. The analysis applied the Life Cycle Assessment (LCA) technique in its attributional modality, focusing on a cradle-to-gate scope for producing 1.0 tons of cement. Primary data from Brazilian cement and steel plants were utilized to create inventories of environmental loads for both materials. Peripheral aspects of the systems, such as utilities and transportation, were modeled using secondary data harmonized with related information. The carbon footprints were estimated using the calculation method outlined in IPCC AR6 (IPCC 2021 GWP). The results revealed that the CP III cement demonstrated a 64% reduction in carbon emissions compared to CP V, equating to a decrease of 600 kg CO2 equivalent per ton of cement produced.

Carbon emissions reduction through open loop recycling of KR slag in road construction

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The construction industry is one of the largest contributors to global environmental impact, responsible for significant consumption of raw materials, energy, waste generation, and greenhouse gas emissions (Wieser et al., 2021). In response to these challenges, the reuse of waste and coproducts in road construction has emerged as a viable alternative, not only to reduce the use of virgin and non-renewable raw materials but also to prevent the disposal of these waste materials in landfills.

In this context, the aim of this study was to assess the reduction carbon footprint achieved by using KR slag, a coproduct derived from KR desulfurization slag, in the sub-base of pavements, based on a Life Cycle Assessment study. The analysis was conducted using both primary and secondary data from the steel industry, highway concessionaires, and relevant literature. The carbon footprint calculation was performed using the ReCiPe 2016 methodology. The results indicated that using KR slag in pavements avoids the emission of 0,18 kg of CO2 per kg of coproduct compared to conventional materials used in this type of pavement, such as gravel and cement. Considering the most recent application quantities (last 6 years), ArcelorMittal Tubarão has avoided the emission of approximately 15.4kt of CO2 equivalent. This application represents about 10% of the KR slag destination, suggesting that emission avoidance could be further increased. The findings highlight the potential of using industrial coproducts, such as KR slag, in construction, not only as a cost-reduction alternative but also as an effective strategy for mitigating the environmental impacts associated with road construction.

Aligning Decarbonization Strategies of Automotive Steel Structures with Absolute Sustainability Goals

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Steel production significantly contributes to global emissions primarily due to its energy-intensive production processes. Despite this, steel remains indispensable to automotive industry owing to its broad availability, well-established supply chains, and recycling infrastructure. In the automotive sector, new vehicle generations often introduce heavier chassis designs to meet stringent safety, performance, and comfort requirements. Consequently, as the demand for steel in automotive structures rises, addressing the sector's environmental impact becomes increasingly vital, especially as OEMs implement stringent decarbonization strategies that must be met.

Achieving this reduction requires a comprehensive approach that balances growing material demands with sustainable production routes while aligning with absolute sustainability goals. Multiple production routes, like using renewable electricity sources for electric arc furnaces to hydrogen-based steel, have been a central point of decarbonization strategies in steelmaking. Absolute sustainability defines operating within planetary boundaries, ensuring ecological limits are not exceeded. Applying this concept to decarbonization strategies for automotive steel production remains under explored and warrants further investigation.

This study shows potential of using different steel production technologies and increased use of recycled steel to meet absolute sustainability. For this, the study examines the carbon emissions associated with an average chassis design composed of various steel grades under cradle-to-gate conditions. Using bottom-up and top-down methodologies within framework of absolute sustainability, we quantify emissions and assess their contribution to potential reduction strategies of automotive structures. The results show that increasing the share of recycled steel and adopting greener production technologies, such as hydrogen-based steelmaking or renewable energy integration, can assist in achieving absolute sustainability targets of producing chassis. By applying these insights, we establish realistic and actionable carbon footprint targets for steel in automotive applications. These findings provide the automotive industry with a status quo and clearer roadmap to meet decarbonization goals, offering a practical guide for advancing sustainability efforts.

Life Cycle Assessment of Fluff Residue Gasification as a Substitute for Natural Gas

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The global steel industry has significantly contributed to climate change, accounting for 7–9% of global greenhouse gas (GHG) emissions. With projected growth in per capita steel demand, the sector has faced the critical challenge of reducing its carbon footprint. Steel scrap recycling has proven to be a key strategy for decarbonizing the steel industry. By decreasing the need for virgin ore extraction and the energy-intensive production of primary steel, recycling has delivered significant environmental benefits.

However, the processing of shredded scrap generates a residue called Fluff, which is typically landfilled. Fluff, a low-density fraction of shredded scrap, consists of materials such as plastics, rubber, and wood. Due to its low density and large particle size, Fluff is separated from heavier metal fractions during shredding, with granulometric and non-ferrous separation processes, such as Eddycurrent, playing a vital role in

this process.

This study focused on the gasification of Fluff and its application as a substitute for natural gas, specifically in billet reheating during steel production. Environmental impacts of this substitution were assessed using Life Cycle Assessment (LCA), based on data from a semi-integrated steel plant and pilot-scale tests in a gasifier.

The study identified an environmental gain in terms of GHG emissions since Fluff contains 12% biogenic carbon. Additionally, eliminating Fluff disposal in landfills further reduced emissions associated with final disposal, resulting in a more favorable environmental balance. The LCA methodology provided a detailed and scientific evaluation of the environmental impacts throughout the material's life cycle, supporting the potential environmental benefits of replacing natural gas with syngas derived from Fluff.

Laser texturing for complex multifunctional metallic surfaces: LCA and sustainable-by-design decision making in the SYNTECS project

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The SYNTECS (Sustainable and Digitally Driven Hierarchical Laser Texturing for Complex Surfaces) project intends to develop a machine platform which enables several micro to nano-structured laser textures on metallic surfaces. Among the objectives of the project, the environmental impacts (global warming potential; human toxicity; mineral resource scarcity) of both traditional (e.g. CNC milling) and laser-assisted technology were obtained through LCA analysis and evaluated. LCA was developed for three case studies, i.e. in the automotive (steel injection molds), medical (titanium hip implant) and thermal management (copper-based complex vapor chamber) industries.

In this paper, the LCA results and the impact categories and relative emission factors of the different case studies (in conventional and laser scenario) are reported. Furthermore, an innovative LCA-CAD plug-in for FreeCAD software, was developed and is here presented. This tool aims at providing a user-friendly tool to non-environmental specialists (e.g. industrial designers). The plug-in enables to select a set of possible best solutions, when choosing e.g. operational parameters of the laser devices, specific laser texturing and required functionalities, and connect them to environmental information. We intend thus to provide a tool for the designer to make informed, sustainable product design decisions.

Results showed that the application of laser surface textures contributes to enhance the efficiency, durability and sustainability of the three case studies. The optimization and miniaturization of (hierarchical) laser-generated surface structures, coupled to eco-design tools, open the possibility for innovative and sustainable surface functionalisation also in a wider industrial environment.

Nexans - Life cycle management for reuse/recycling of metals

Shifa Meyer

Nexans, France

Introduction:

Nexans is a leader in the design and manufacturing of cable systems and services, we are paving the way towards the new world of electrification: safer, renewable, low carbon and accessible to all.

Nexans has been so far implicated in circular economy through:

- End of life management: collecting and recovering cable scraps
- Integration of recycled content in products

Nexans new model: Recycling services for Professionals

Nexans has launched the proof of concept for professionals, a new business model for collecting and recycling cable scrap directly from our partners' branches.

With this new service, Nexans will be able to expand its recycled content in cables addressing the challenges of circularity and contributing to strengthen our position as a pioneer in sustainable development and a key player for recycling in industry while innovating with new services for our partners and generate value for all our stakeholders

The initiative came to life in November, with the installation of 5 recycling booths in Sonepar & Rexel branches, in France. The test is scheduled to last 6 to 12 months.

This system, which generates new physical flows, capitalizes on :

Reverse logistics of our partners in order to centralize scrap on their platform

Existing flows managed for Enterprises to transport waste to Lens

This new service comes up against the long-established habits of electricians, who favor other channels for recycling their cables (scrap metal dealers). It's a new approach that needs to be inculcated to reinforce the circularity of metals in our industry.

Conclusion:

Circular economy with the integration of secondary resources such as recycled copper in substitution for primary resources, offers an opportunity to reduce Nexans' dependance on natural resources, to lessen the Group's environmental impact and to decarbonate cable systems, leveraging Nexans's endtoend Vertical Integration from metallurgy to cable recycling.

Session 3.04: LCSA Insights: Actionable Solutions for Global Challenges

Time: Friday, 12/Sept/2025: 9:35am - 11:05am
Session Chair: Jana Gerta Backes, Meo Carbon Solutions GmbH, Germany
Session Chair: Alessandra Zamagni, Ecoinnovazione, Italy

LCSA for identifying material sustainability topics and risks in value chains

Hanna Pihkola[1], **Marina Isasa**[2]

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Within companies, LCSA can be applied to support product and technology development, life cycle management and sustainability related strategy building. Findings from the European project ORIENTING revealed that LCSA can be particularly useful for learning about sustainability impacts in the value chain, identifying material sustainability topics and providing extensive environmental and social information that can be later used to respond to the requirements of the Corporate Sustainability Due Diligence (CSDDD) and the Corporate Sustainability Reporting (CSRD) Directives. Sustainability topics to be measured and reported by a company, according to the CSRD, are defined based on a double-materiality assessment covering both financial and sustainability perspectives.

This contribution presents the ORIENTING LCSA methodology focusing particularly on how the idea of materiality assessment was incorporated (1) to focus on the goal and scope to keep the workload manageable and (2) to understand the materiality of different sustainability impacts as part of interpretation of LCSA results.

The findings from the project (including five industrial case studies), indicate that when applying LCSA for the first time, it is important to start from internal applications, to get to know the methods and to invest in collecting the necessary data from the value chain. It is useful to first conduct internal LCSA studies as benchmarks to understand which are material sustainability topics for the product, and to start mapping the value chain and related stakeholders. When becoming familiar with the methods and data required, more advanced assessments can be conducted, and the usability of the results increases. After gaining sufficient experience and data for conducting robust LCSA studies, LCSA can become very useful for sustainability communication and responding to regulatory requirements. However, using LCSA for making comparable sustainability claims is currently hindered due to lack of guidelines and procedures for review and verification of LCSA studies.

Holistic and Integrated Life Cycle Sustainability Assessment (HILCSA): Background, Results from Case Studies and Future Developments

Walther Zeug, Andrés Murillo

Helmholtz-Centre for Environmental Research (UFZ), Germany

The current socio-ecological crisis is reflected in the unequal satisfaction of societal needs which are directly linked to a massive transgression of planetary boundaries. To address this challenge, we developed an integrated sustainability framework with clear and applicable definitions of social, ecological and economic sustainability and in order to assess and analyze it, we developed, implemented and validated the 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, using the Ecoinvent/SoCa database and HILCSA is licensed for commer.cial and educational use. To date, HILCSA has been applied in two case studies: a) a comparison of wood with steel beams showed that renewable bio-based construction materials can have a better holistic sustainability than fossil-based ones; b) we compared liquid biofuels with fossil fuels in the transport sector, showing some contributions to the SDG but significant sustainability risks in terms of land and water use, energy efficiency, working conditions and maintaining problematic global supply chains.

Future developments of HILCSA aim for an absolute sustainability LCSA considering planetary boundaries and socio-economic limits as budgets for nations, regions, sectors and organizations.

Metal in Motion: Reviewing Predictive Models for Metal Demand in the Energy and Digitalisation Transition

Rhani Bostyn, Ricardo Magdalena Zarzuela, Hellen Louisa de Castro e Silva, Jo Dewulf

Ghent University, Belgium

The global push for energy transition and digitalisation is fuelling an unprecedented demand for critical and strategic metals. This presents significant challenges and opportunities, requiring future-oriented solutions. The EU's "twin transition" initiative, illustrated by the Global Gateway Strategy, aims to create resilient supply chains, promote sustainable resource use, and reduce dependence on non-renewable materials, particularly in the European Union. Several metals, including lithium, cobalt, and rare earth elements, are crucial for renewable energy systems, electric vehicles, and digital infrastructure.

Metal recyclability and the growing demand become essential in accurately forecasting future needs. Developing reliable predictions for this twin transition calls for detailed modelling approaches. However, existing methods differ widely in their scope, methodologies, and boundary conditions. Some models incorporate circular economy principles such as recycling, evolving policies, and material substitution, while others rely on static, linear frameworks that overlook these interconnected dynamics. This variability complicates efforts to create robust forecasts. Therefore, harmonising modelling frameworks is essential for consistent and actionable insights into metal flow management for the next years.

This paper presents a comprehensive review of dynamic metal flow models, assessing their capacity to forecast metal demand across various future timeframes. Through a systematic approach, key methodological differences were highlighted, revealing gaps regarding the integration of technological evolution, socio-economic factors, and policy-driven considerations in current models. Thus, the results obtained in this study could serve as a baseline for predicting metal demands, which would help policymakers and industry stakeholders to address the complexities of sustainable metal resource management in the energy and digitalisation transition.

An ex-ante Life Cycle Sustainability Assessment of a lithium recovery process from exhausted batteries

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In recent years, lithium-ion batteries (LIBs) have become essential for the decarbonisation of the automotive sector, leading to a rapid growth in their usage worldwide. However, as LIBs contain multiple critical raw materials (CRMs) beyond lithium, there is a growing need for sustainable technologies capable of recovering these substances from batteries at their End-of-Life (EoL) and reintroducing them in the economy, through a circular approach. In this perspective, the present research evaluates the overall sustainability of

a patented hydrometallurgical process meant to recover lithium, cobalt, nickel, iron, and manganese from exhausted LIBs. The environmental, economic and social impacts of the process are assessed through the Life Cycle Sustainability Assessment (LCSA) methodology with an ex-ante approach. Indeed, even though the process has only been tested at the bench-scale so far, the repercussions on all dimensions of sustainability are estimated at an industrial level, assuming the treatment of 1000 tons of wasted LIBs over a year, by elaborating primary data provided by the process developers, through environmental and economic upscaling frameworks (e.g., Piccinno et al., 2016; Turton et al., 2002). The analysis identifies the environmental, economic and social benefits of recycling CRMs from batteries, instead of using virgin products and treating LIBs in landfills, especially regarding the reduced abiotic depletion, acceptable costs, and adequate working conditions. Besides, the use of circular economy-oriented impact categories enables to determine feasible improvements for the process, in order to recover additional resources and energy, to increase the obtained revenues, and to minimise the burdens on the community. Therefore, the synergy between the LCSA approach and the upscaling frameworks proves to be a useful tool, both for the evaluation of the sustainability of a novel technology before its further advancement to the industrial scale and for boosting its contribution to the circular economy.

Advancing Sustainable Cultural Heritage Preservation through Life Cycle Sustainability Assessment: Insights from the MOXY Project

Dieuwertje Schrijvers[1], Noura Rahbani[1], Naeem Adibi[1], Marta Cremonesi[2], Catarina Pires[3], Nan Yang[2], Klaas Jan Van den Berg[3], Ilaria Bonaduce[4], Michaela Florescu[5], Nina Olsson[6], Geert Van der Snickt[2], Ana Sobota[7], Tomas Markevicius[8], Anton Nikiforov[8]

[1]WeLOOP, France; [2]University of Antwerp, Belgium; [3]University of Amsterdam, the Netherlands; [4]University of Pisa, Italy; [5]Moderna Museet, Sweden; [6]ICOMOS Lietuva, Lithuania; [7]TU Eindhoven, the Netherlands; [8]Ghent University, Belgium

Cleaning methods currently used in conservation of cultural heritage often pose risks to delicate artefacts due to their reliance on chemicals and physical contact. The MOXY project, funded under the Horizon Europe call “Green Technologies and Materials for Cultural Heritage”, proposes an innovative alternative using non-contact atomic oxygen (AO) technology to safely remove carbon-based contaminants. This approach aims to protect irreplaceable cultural assets while promoting more sustainable conservation practices.

This presentation shares findings from the Life Cycle Sustainability Assessment (LCSA) of the MOXY AO treatment, comprising environmental LCA, Social LCA, and Life Cycle Costing. The AO technology allows cleaning sensitive cultural heritage (CH) objects that could not be treated otherwise. However, the environmental benefits of the technology are difficult to quantify, as “cleaning with AO” obviously results in a higher environmental impact compared to “not cleaning”. This, however, would result in the loss of CH, arguably considered a non-renewable resource. This limitation in the LCA methodology must be considered in the interpretation and use of LCA results applied to CH. Even though CH is now considered in the Social LCA framework, a focus is put on potential damage to CH caused by product systems, rather than a quantifiable trade-off between damages to the natural ecosystem and benefits to cultural heritage, i.e. the man-made ecosystem.

Furthermore, the environmental performance of AO treatment notably depends on the component lifetime and frequency of use of the device, both influenced by user behaviour and business models. For example, leasing models could increase the economic accessibility of the device while decreasing its environmental impacts. Besides, a device will never be “green” if its use is limited by high purchasing costs. Therefore, we stress the importance of a joint evaluation of environmental, social, and economic factors, as social and economic challenges may annihilate theoretical environmental gains.

Session 3.05: Regional Sustainability via Life Cycle Instruments Part II

Time: Friday, 12/Sept/2025: 9:35am - 11:05am
Session Chair: Takunda Yeukai Chitaka, University of Bordeaux, France
Session Chair: Pia Wiche, EcoEd, Chile

Territorial Life Cycle Assessment of the Battery Sector in the Hauts-de-France Region: Revisiting Predictions with 2024 Updates

Emilie GUILVERT[1], Noura RAHBANI[1], Christian TRAISNEL[2], Guillaume SZABLEWSKI[3], Naeem ADIBI[1]

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In 2022, WeLOOP conducted a Territorial Life Cycle Assessment (TLCA) of the electric vehicle battery sector in the Hauts-de-France (HdF) Region, as the area prepared for the opening of three battery Gigafactories. The study aimed to evaluate environmental and social, impacts while providing a roadmap for integrating circular economy principles. However, two years later, the landscape has evolved significantly: some projects have progressed, others have faced delays, and new initiatives have emerged, changing the regional dynamics.

The 2022 TLCA envisioned three scenarios—"follower," "actor," and "leader"—to forecast the potential outcomes of different strategies for the regional battery sector. The "follower" scenario relied on imported raw materials without local recycling or reuse. The "actor" scenario introduced moderate improvements, meeting EU recycled content targets and incorporating limited battery refurbishment. The "leader" scenario outlined an optimized value chain with local reuse, recycling, and material refinement, surpassing EU regulations in efficiency and recycled content. These scenarios highlighted a potential 26% reduction in environmental impacts between the "follower" and "leader" approaches, driven by increased recycling and reduced reliance on primary materials.

As of 2024, many assumptions made in the initial study require reevaluation. Some projects have experienced delays, new actors have entered the sector, and shifting priorities have influenced regional strategies. The updated TLCA will compare the current state of the battery sector against the 2022 predictions, assessing how these changes have impacted the region's progress toward sustainability goals.

This retrospective analysis will refine the TLCA methodology, integrate the latest data, and provide stakeholders with actionable insights. By evaluating the deviations from initial predictions, the updated study aims to guide the HdF Region in recalibrating its approach, reinforcing its commitment to building a sustainable and circular battery economy.

Building Competency for Sustainable Industry: The Development of Indonesia's National LCA Practitioner Standard

Jessica Hanafi[1,2], Ellyna Chairani[2,4], Dian SR Kusumastuti[3], David Adiwijaya[1], Gloria FJ Kartikasari[1]

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With the growing demand for Life Cycle Assessment (LCA) knowledge and practitioners globally, a standardized framework for competencies is essential to ensure reliable LCA applications. This paper explores the development of Indonesia's national competency standard for LCA practitioners—the first of its kind globally. Achieved through a multi-stakeholder effort (2021–2023) and officially issued by the Ministry of Manpower of the Republic of Indonesia as the National Work Competency Standard in August 2024. This standard defines 12 competency units to ensure adherence to LCA methodologies. Spearheaded by the Ministry of Environment and Forestry Human Resources Planning and Development, the Standard aligns with ISO 14040, 14044, and ISO 14071, providing a procedural guide for rigorous LCA assessments and verification.

The framework identifies units of competency, elements of competency, and performance criteria, incorporating critical aspects of knowledge, attitudes, and skills to address both technical expertise and the mindset required for quality assessments. Upon approval by the Ministry of Manpower, the standard will formalize its integration into national workforce frameworks and apply to three occupational roles—LCA Practitioner, Verifier/Critical Reviewer, and Executive—critical for effective LCA implementation.

In addition to strengthening the Indonesian industrial sector, the Standard aims to support global sustainability initiatives, including carbon market mechanisms, by aligning with international certification frameworks. The paper highlights the structured development process, from stakeholder engagement to final approval, and addresses anticipated impacts on the Indonesian industrial sector. It also explores challenges, such as maintaining consistency and reliability in certification while balancing the growing demand for practitioners with high-quality standards. By introducing the world's first national competency standard for LCA, this initiative represents a significant step toward integrating sustainability principles into industrial decision-making and advancing Indonesia's leadership in global sustainability.

Territorial life cycle thinking for sustainable urban development: Application and learnings from an urban food system in Flanders (Belgium)

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Food systems are increasingly seen as territorially embedded – bound to their existing geography and governance structures – and environmentally impactful. Action to improve their environmental sustainability is often impelled by normative decisions rather than life cycle thinking. Territorial Life Cycle Assessment (T-LCA) is a science-based methodology that evaluates environmental impacts across delineated geographic boundaries, enabling administrative authorities and agri-food stakeholders to make informed, data-driven decisions. With most applications occurring in the French context, this contribution showcases the implementation of T-LCA in an urban food system in Flanders (Belgium), synthesising publicly available national, regional, and municipal data. By taking a food production and consumption perspective, food-related activities included in the scope were agricultural production, manufacturing, consumption, and waste. The study aimed to provide a 'snapshot' of environmental impacts in a reference year to benchmark food-system impacts and understand contextualisation and methodological decisions. Impacts were assessed for 16 indicators with the Environmental Footprint (EF) 3.1 impact assessment method, including normalisation and weighting. The results showed that impacts were driven by food consumption (52%), particularly animal-derived food products, followed by local food manufacturing (46%). For food consump-

tion, several modelling options emerged, particularly actual consumption from national consumption surveys or apparent consumption (i.e., production + imports - exports) using impact assessment results from existing consumption studies. A sensitivity analysis showed large discrepancies between consumption approaches, with a daily climate change impact range of 2.7-9.3 kg CO2 eq per capita. In food production and manufacturing, important methodological considerations were the inclusion criteria for agricultural outputs and food processing companies. This example highlights the methodology's relevance in measuring city-level food-system-wide impacts and taking action to mitigate these, as well as methodological choices, contextualisation parameters, and means to overcome data and time constraints inherent in the methodology.

Extended Life Cycle Assessment Ecosystem Services Method for Urban Green Infrastructure

Alana Teresa Griggs, Joy Winbourne, Alessandro Sabato, Jasmina Burek

University of Massachusetts Lowell, United States of America

Cities are implementing urban green infrastructure (UGI) such as parks, gardens, and green roofs for the suite of ecosystem services (ES) they provide including carbon sequestration, air quality improvement, urban heat island mitigation, and enhanced biodiversity. Quantification of net benefits and costs are crucial for effectively communicating the advantages of these systems to stakeholders, and for comparing various UGI. Food forests are multifunctional agroforestry systems that feature diverse edible plants and offer a promising alternative to conventional lawns, which are the business-as-usual greenspace globally. Despite their potential, the net benefits and trade-offs of urban food forests remain underexplored. Additionally, life cycle assessment (LCA) methods fail to fully integrate ES, leading to an undervaluation of UGI. This research aims to fill these gaps through the creation of an extended LCA ES method for UGI that explicitly accounts for the inclusion of two ES: 1) local climate regulation by urban heat island mitigation and 2) global climate regulation by greenhouse gas emissions regulation. Our approach leverages empirical data from instrumented case studies at the UMass Lowell Food Forest and an adjacent urban lawn. ES are integrated in the LCA standardized framework in the life cycle inventory and impact assessment phases through midpoint characterization. Midpoint categories for integration of global climate regulation impacts exist in LCA, but not for local climate regulation, thus a new midpoint category and method for integration is developed. Sensor-derived data informs the methods development and validates its application. The expected outcomes from the proposed integration approach include: (1) a more complete view of environmental impacts and benefits of food forests from the integration of ES with LCA, (2) quantitative and actionable data on the environmental benefits of urban food forests to inform policymakers and urban planners (3) a replicable framework for assessing impacts and benefits of other UGI.

Plastic waste upcycling to mitigate environmental impacts in a developing country context

Poppy Dent[1], Rose Nangah Mankaa[2], Manoj Palani Kumar[2]

[1]Trashy Bags Africa, United Kingdom; [2]INaB-RWTH Aachen

The plastic pollution problem spans internationally, affecting the environment on a massive scale including social and economic consequences. Improper handling of plastic waste in numerous African urban and rural areas pollute water sources, destroy animal habitats and also create environments conducive for malaria vectors. In Ghana, plastic waste leads to clogging of waterways, littering landscapes, and risks to human and ecosystem health. Of the 2.58 million tons of unprocessed plastics entering Ghana annually, only 5% is recycled, resulting in widespread littering. Nearly 30% enters the ocean constituting marine plastics, while the rest litters the landscape or ends up in landfills. Water sachets, a prevalent form of packaged drinking water, significantly contribute to this challenge due to their single-use nature and lack of recovery or reuse

practices by Ghanaian households and the informal sector. Water sachets provide affordable drinking water and support economic livelihoods, highlighting the tension between economic needs and environmental sustainability. The missing link is the lack of proper plastic waste management systems leading to civil society and private sectors embarking on plastic reuse and recycling.

This study seeks to provide insightful information on the environmental impacts of such activities according to the ISO 14040/44 framework. Hence, the transformative approach of the small-scale enterprise "Trashy bag Africa" is investigated. The system boundary encompasses the collection of plastic waste from the streets of Accra, its transportation to the Trashy Bags Africa and the subsequent processing into finished marketable products. This analysis identifies key hotspots within the value chain highlighting opportunities for improvement in the company as well as the benefits of reuse and resource recovery in developing countries. The findings strengthen and further operationalize the circular economy and upcycling concepts embedded in the Ghanaian National Plastics Management Policy and the National Plastics Action Roadmap.

Circular systems for a sustainable region – Pioneering stronger collaboration

Annik Magerholm Fet, Siv Marina Flø Grimstad, Ajay Kumar

Norwegian University of Science and Technology, Norway

The Norwegian County Møre and Romsdal aims to be among the best regions in terms of sustainable development. It has the strongest industrial clusters within the maritime and marine sectors with the highest share of export in Norway.

As part of this, funding has been granted for six PhD position, and their research will contribute to capacity building, new knowledge and innovation that promotes sustainable and green regional solutions. To achieve this, networks and interaction between research fellows, private and public enterprises, academic institutions will be focused.

The Regional Development Plan for the region points out that sustainable solutions are an increasingly strong driver for societal and business development. Innovation often takes place at the intersection of disciplines, sectors and industries. It is therefore becoming even more important to seek cross-disciplinary cooperation. More efficiently use of resources should be possible by circular solutions. In addition, one will emphasize that green and circular transition must be profitable for both companies and the society in the long term, and that knowledge must be built for a long-term transition. The program is called "Sustainable Solutions for a Sustainable Region". The results will among other, be used to increase the competitiveness of the industries in the region under increasingly complicated regulations.

Examples of research topics will be "What is the scope of "circular systems" and its relevance to cross sectoral research?", "How to go from linear to circular models of the different value chains?" and "How to organize industrial symbioses for increased resource efficiency?".

The presentation will give examples from the various industries on solutions that can lead to sustainability circularity actions in the region focusing on e.g. LCA training and its usability for regional circularity and in combination with other LCM-tools.

Freshwater and marine eutrophication in tobacco cultivation in brazil: a case study

Vanderlise Giongo[1], Adão Da Silva Acosta[1], Álvaro Augusto Dossa[1], Anderson Santi[1], André Júlio Do Amaral[1], Diego Inácio Patrício[1], José Eloir Denardin[1], Maria Cléa Brito De Figueirêdo[1], Marília Ieda Da Silveira Folegatti[1], José Paulo Pereira Das Dores Savioli[1], Amanda De Oliveira Andrade[2], Mônica Da Silva Santana[1,3]

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Growing concerns about eutrophication and its impact on life have intensified global pressure to promote more sustainable agriculture. Tobacco production is a significant global activity, with an estimated production of 6.4 million tons in 2023/2024 across 4 million hectares. Brazil is the third-largest producer, with 683.5 thousand metric tons in 284,184 ha. Life Cycle Assessment (LCA) is a tool for identifying critical environmental impacts and opportunities to reduce pressure on natural resources. This study aimed to analyse freshwater and marine eutrophication resulting from the cultivation of Brazilian tobacco. Data over four years were collected from two farms in the South of Brazil, a region responsible for approximately 95% of country production. The functional unit was the production of 1 kg of dry tobacco. Eutrophication impacts were analysed using the ReCiPe 2016 Endpoint (H) 1.09 method and the SimaPro 9.6.0.1 software. Freshwater eutrophication ranged from 1.28E-04 to 1.37E-04 kg of P eq, while marine eutrophication ranged from 4.57E-03 to 7.04E-03 kg of Neq. Nitrogen and phosphate fertilisers accounted for 58 and 26% of the impacts for the freshwater eutrophication category. In contrast, for marine eutrophication, field emissions were more significant (96 to 98%), mainly due to the transformations that N undergoes in the soil. The impact of field emissions and fertilisers on eutrophication categories is expected, as they are categories that measure the amount of P and N released to water bodies. While fertilisers are essential to achieve productivity targets, their production must become cleaner and their application more efficient to ensure sustainable agriculture. Slow-release fertilisers combined with biological alternatives, such as phosphate-solubilising inoculants and nitrogen-fixing cover crops, can be used as strategies to mitigate eutrophication impacts in Brazilian tobacco cultivation.

Session 3.06: Nutritional LCA for Sustainable Agri-Food Management Part II

Time: Friday, 12/Sept/2025: 9:35am - 11:05am
Session Chair: Gianluca De Nardi, EcorNaturaSì Spa, Italy
Session Chair: Silvia Zingale, Agroscope, Switzerland

Environmental sustainability of aquafeed formulations enriched with Black Soldier Fly oil

Sara Silva[1], Maria J. Mota[2], Paula Quinteiro[1]

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The aquaculture industry's dependency on fishmeal and fish oil contributes to the overexploitation of wild fish stocks and related environmental impacts, driving the development and adoption of sustainable feed alternatives. Black soldier fly (BSF) protein meal and oil arise as feed alternatives. BSF oil is a promising substitute for fish oil due to its nutrient-rich profile, including lauric acid, which supports fish health, metabolism, growth, and feed efficiency.

This study applies a life cycle assessment (LCA) methodology to quantify and compare the environmental performance of a conventional aquafeed formulation and an innovative aquafeed-based BSF oil formulation for seabass production, from a cradle-to-gate perspective. The functional unit was defined as 1 t of aquafeed and the Environmental Footprint (EF) method v3.1 was used. Primary input data were acquired based on surveys of a representative aquafeed production mill in Portugal. Preliminary results show that aquafeed-based BSF oil formulation presents higher environmental impacts than conventional aquafeed across most assessed impact categories, primarily due to the production of insect feed (side streams from the agro-industrial sector), and electricity consumption for insect farming and processing. These findings highlight the need to evaluate and implement improvement measures, such as integrating photovoltaic panels to reduce fossil-based electricity production. Future research should incorporate feed efficiency, measured by the feed conversion ratio (FCR)—the quantity of feed required for unit weight gain—in seabass production to enable a more comprehensive environmental sustainability assessment. Such insights are essential for evidence-based decision-making.

Incorporating nutritional constraints in evaluating environmental consequences of new ingredients transformed from residual biomass in future feed and livestock systems

Gleeza Manulat[1], Florence Garcia- Launay[2], Caroline Sablayrolles[3], Lorie Hamelin[1]

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Life cycle assessment (LCAs) on residual biomass for animal feed highlights significant environmental benefits, particularly by avoiding protein feed ingredients. However, most LCAs neglect nutritional constraints, treating animal requirements as a black box- assuming uniform nutrient requirements across species. To address this, we integrate animal nutrition science with LCA by coupling market-based feed formulation and consequential LCA to account for nutritional constraints on the environmental effects of new ('waste'-based) ingredients. To demonstrate our approach, we evaluated displacement effects of five

new ingredients (NIs): (1) single-cell protein from bacteria fed methane from manure anaerobic digestion (SCP-ADM), (2) mycoprotein from fungi grown on wheat straw-derived fermentable sugars (MYCP-WS), (3) solid-substrate fermented rapeseed meal (SSF-RSM), (4) green protein concentrate from sugar beet leaves (GPC-SBL), and (5) black soldier fly larvae reared on food waste (BSF-FW) in compound feeds (CF) for broilers, pigs, sows, and rainbow trout. Downstream impacts on manure excretion and animal performance were also considered. Compared to state-of-the-art (SOTA) feed substitution models used in prior LCAs, SOTA overestimates savings for SCP-ADM and BSF-FW in climate change (CC: +35–59%), marine eutrophication (MEP: +100%), and land use (LU: +70%), while no general trends are observed for other NIs and impacts. CFs incorporating NIs, particularly CFs with SCP-ADM and GPC-SBL have systematically lower impacts compared to CFs with conventional feed ingredients, primarily due to reduced soybean meal use and the inherently negative unit impacts of SCP-ADM for CC and GPC-SBL for MEP and LU. Production of SCP-ADM avoids conventional manure management as manure is used to produce biogas for SCP-ADM (CC), and GPC-SBL displaces cow forage with its co-produced fiber product (MEP, LU). Furthermore, downstream effects show negligible effects than upstream impacts. These findings along with insights on performance dependency will be confirmed in the next stages through uncertainty and sensitivity analysis.

Environmental assessment of avocado (Persea americana) production in different biomes throughout Peru

Ian Vázquez-Rowe, Álvaro Elorrieta, Joan Sanchez-Matos, Jorge Bentín, Ramzy Kahhat

Pontificia Universidad Católica del Perú, Peru

There is rising concern regarding certain environmental impacts of avocado production such as water scarcity and greenhouse gas (GHG) emissions, but also to deforestation or land degradation. Avocado production in Peru takes place in a diverse set of biomes and agroforestry systems. Therefore, it is important to understand differences in the environmental profile of avocado production within the diversity of these cultivation systems. Hence, the main objective of the study was to conduct a cradle-to-gate Life Cycle Assessment of avocado production in Peru, under multiple scenarios and focusing on supply chains, to provide insights for enhancing its environmental performance. SimaPro was used to integrate the inventories and assessment methods, with ReCiPe 2016 applied to evaluate impact categories such as eutrophication and acidification, and IPCC 2021 employed to estimate GHG emissions. Water scarcity was analyzed using the AWARE method, incorporating Peruvian-specific characterization factors (CFs). Biodiversity impacts were evaluated through a set of indicators, including the LUIS biodiversity footprint. Results were then complemented with uncertainty and sensitivity analyses. GHG emissions, which include carbon capture, ranged from 156 to 737 g CO2eq/kg, depending on the avocado variety assessed, within a middle range for fruits and vegetables as compared to the global literature. Agroforestry systems showed lower impacts compared to monoculture systems, particularly in carbon sequestration and land use. Water scarcity ranged from 71 to 333 m3eq/kg, depending on regionalized CFs, whereas BF methods suggest that avocado cultivation poses greater risks to the Amazon rainforest and the Andean Highlands as compared to the coastal desert. For both water scarcity and biodiversity, results were highly site-specific, and spatial resolution is needed for decision-making on a case-to-case basis. Optimizing fertilizer use and adopting efficient irrigation methods were identified as key strategies to reduce environmental burdens across all systems.

Eight Building Blocks for Reliable and Widespread Carbon Footprints in Agri-Food Supply Chains

Koen Deconinck[1], Saule Burkitbayeva[2], Hillena Thoms[3]

[1]OECD, France; [2]Australian National University; [3]European University Institute

What would it take to achieve widespread and reliable information on carbon footprints of agri-food products? Recent work by the OECD argues that eight building blocks are essential. Reporting standards, science-based methods, farm-level calculation tools, and databases with secondary data are needed to calculate carbon footprints, but these must be complemented with ways to communicate carbon footprint data along the supply chain, ways to ensure the integrity and quality of the data and calculations, ways to scale up carbon footprint calculations while keeping costs low, and ways to update all these elements as scientific insights and technologies evolve. The magnitude of the challenge should not be underestimated. But many of the building blocks are falling into place and can be improved and aligned through collaboration between researchers, farmers, other supply chain actors, governments, and civil society, both at domestic and international levels. The presentation will also update participants on ongoing work by OECD member states to harmonise existing approaches.

Integration of environmental and nutritional aspects into Life Cycle Assessment: a proposal for durum wheat pasta

Silvia Zingale[1,7], Alba Reguant-Closa[1], Margherita Dall'Asta[2], Gianluca Giuberti[3], Gianluca De Nardi[4,5,6], Paolo Guarnaccia[7], Carlo Ingrao[8], Thomas Nemecek[1]

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Sustainable food systems are essential to nourish the growing global population within planetary limits, and staple cereals play a key role in this transition, as they have a significant environmental impact but are also crucial dietary components. This study aims to evaluate the environmental and nutritional performances of different durum wheat-based pasta products through a nutritional Life Cycle Assessment. The study's novelty lies in proposing a new nutritional index specific to pasta and assessing the effects of integrating this index into the LCA results. A cradle-to-fork approach was adopted, and the ReCiPe 2016 v. 1.04 methodology was used at the midpoint and endpoint levels, assuming a hierarchical perspective. The results demonstrated that the index effectively differentiated the nutritional profiles of the pasta products. Furthermore, when the functional unit was shifted from mass-based to nutritional, the environmental impacts were amplified, and the ranking of the investigated products changed significantly. This underscores the importance of integrating nutritional considerations into LCA and acknowledging the role of complementary foods in a balanced diet. Cooking emerged as the dominant environmental hotspot, contributing approximately 70% of the total impact, primarily due to energy consumption, followed by the cultivation phase, with land occupation being the most impactful process due to the relatively low yields under organic farming practices. Key impact categories included Global Warming, Human Health, Fine Particulate Matter Formation, Land Use, Terrestrial Ecosystem damage, and Fossil Resource Scarcity. Relevant trade-offs between productivity at the field level and the final product's nutritional quality were identified, emphasizing the need for strategic interventions to balance these aspects within pasta production systems. Accordingly, the study proposes targeted mitigation strategies for the most relevant stakeholders, including producers, processors, and consumers, to enhance the overall sustainability of pasta production and consumption.

Life Cycle Assessment of organic dry cocoa beans in Peru

Ian Vázquez-Rowe[1], Eizo Muñoz-Sovero[1], Pablo González-Socorro[2], Jhonnatan Murga[3], Shenali Madhanaroopan[4], Salma Fotovat[4], Taylor Stanley[4]

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Organic cocoa production systems are of interest in Latin America as they are an important source of revenue for farmers and have also shown to have lower environmental impacts than conventional production systems regarding greenhouse gas (GHG) emissions. The current study focuses on providing a cradle-to-gate LCA of the production of organic cocoa beans, considering the cocoa cultivation practices of a group of 21 producers located in central Peru. The functional unit (FU) selected was 1 kilogram of dried cocoa beans ready for use to produce chocolate products. Beyond agroforestry management activities and transport to the processing plant, a full consideration of the biogenic carbon cycle of cocoa production was modeled, including the role of shading trees. A total of 8 impact categories were selected for the Life Cycle Impact Assessment, including carbon and water footprint indicators. Results for GHG emissions show a range of values in line with studies found in the scientific literature, with higher yield cultivation sites with shading close to carbon neutrality. Despite the organic conditions of the farms, the post-harvest management of the cocoa pods appears as a critical source of GHG emissions and derived uncertainty. In fact, adequate composting conditions maintain the emissions of methane at lower levels, but direct return of the pods to the field can generate a two- or three-fold increase in carbon emissions. Carbon sequestration from above ground biomass, mainly from shading trees and, to a lesser extent, cocoa trees, mitigate a fraction of these emissions if shading is homogeneous and sufficiently dense across the cocoa-producing fields. For other impact categories, toxicity emissions at the cultivation site were low given the organic characteristics of the fields. Finally, water scarcity impacts are minor, as cocoa plantations rely entirely on rainfall and water use at the processing plant is limited.

Integrated Health and Environmental Assessment of Japanese Dietary Menus

Genta SUGIYAMA[1], Akito Onoda[2], Sachi Nii[2], Chie Furuta[2], Keiji Nakamura[3], Norihiro Itsubo[1]

[1]Waseda university, Japan; [2]Ajinomoto Co., Inc. Institute of Food Sciences and Technologies; [3]Ajinomoto Co., Inc. Research and Business Planning Dept.

The transition to unhealthy diets has been reported to place significant burdens on both health and the environment. Globally, unhealthy diets are associated with increased risks of non-communicable diseases (NCDs), such as obesity, diabetes, cardiovascular diseases, and certain cancers. Simultaneously, the production and consumption of unhealthy foods often lead to increased greenhouse gas (GHG) emissions, overuse of natural resources, and loss of biodiversity. Particularly, excessive consumption of animal-based and processed foods has been shown to degrade nutritional quality while exacerbating environmental burdens, further compounding these challenges.

Recent years have seen progress in research quantifying the health benefits of healthier diets, focusing on reducing disease risks and improving nutritional balance. However, few studies have conducted integrated evaluations of nutrient intake's health impacts and environmental burdens using a unified indicator, resulting in an incomplete understanding of how health and sustainability goals can be achieved simultaneously.

To address this gap, this study analyzes the relationships between nutritional quality, health impacts, and environmental burdens using three methodologies. Nutritional quality was scored using the Nutritional Profiling System (NPS), designed for Japanese diets. Health impacts from nutrient intake were calculated as Disability-Adjusted Life Years (DALYs) using the GLAM method, a health impact assessment developed by the Life Cycle Initiative. Environmental burdens, including GHG emissions, air pollution, and water consumption, were

evaluated in DALYs using the LIME3 method, a life cycle impact assessment model by Itsubo et al.

This study aims to elucidate the interconnections among Japanese menus evaluated by NPS, health DALYs (via GLAM), and environmental DALYs (via LIME3). The findings contribute to developing sustainable dietary models that align health goals with environmental sustainability. By providing scientific evidence, this research supports policymaking and consumer awareness, promoting sustainable dietary transitions.

Session 3.07: Data Creation & Exchange Tools: Transparency First

Time: Friday, 12/Sept/2025: 11:30am - 1:00pm
Session Chair: Stephan Pfister, ETH Zurich, Switzerland
Session Chair: Emilia Moreno Ruiz, ecoinvent, Switzerland

Methodological Updates for Fuels, Pesticides, Fertilizers and Biogenic Carbon in the Agricultural Sector in the Ecoinvent Database

Francesco Cirone, Simone Fazio, Andreas Giakoumatos, Thomas Sonderegger

Ecoinvent, Switzerland

Ensuring quality and transparency of the Life Cycle Inventory is essential for effective Life Cycle Assessments and regulatory compliance with sustainability goals. Recent updates in the agricultural sector of Ecoinvent aim to improve the precision and reliability of LCI data. The key methodological improvements include:

- Decoupling of Fuel in Agricultural Operations: Fuels were modeled within the whole agricultural operations, with a pre-defined fuel consumption per hectare. In the new approach, it is inventoried separately and always linked to the specific operation, which will be kept as a fixed amount of one or multiple (in case of multiple passes) hectare(s).
- Remodelling of Pesticide emissions: Emissions were previously reported as 100% emissions to soil. The new approach adopts Pest-LCI model to estimate emissions in different compartments (soil, air, and water).
- Split of Multi-nutrient fertilizers (MNFs): MNFs were modeled as whole fertilizers, leading to potential double counting or underestimation for some of the single nutrients. The new approach adopts a pre-modeled split of the single nutrients, also including a specific split of emissions in the production phase, where applicable. It also includes a recalculation of the market(s) for fertilizers.
- Biogenic Carbon rebalancing: To quantify biogenic carbon in biomass growth, properties of elementary exchanges, “Carbon dioxide, in air” (resource), and “Carbon dioxide, non-fossil” (emission) are relevant. The uptake corresponds to carbon in products and byproducts, minus the carbon in products entering the process (e.g. seedlings). Biogenic carbon of intermediate and elementary exchanges is quantified by the mathematical relation between dry mass and carbon content property.

The new approaches lead to low variations in LCIA results at different levels (impact categories and scores). They increase the precision and allow a more intuitive modeling logic for practitioners supporting the continuous evolution of LCI datasets in response to market dynamics and emerging use cases.

New modelling approaches for waste treatment datasets in the ecoinvent database

Sebastian Kjærulff Jensen, Avraam Symeonidis, Emilia Moreno Ruiz

ecoinvent Association, Switzerland

Life Cycle Assessment (LCA) is an essential tool for assessing the environmental impacts of a product, service, or entity by considering its entire supply chain and end-of-life. Waste management through treatment and recycling technologies can have a considerable impact on the environmental performance of a system. LCA of waste management also guides critical decisions on disposal, circularity, and material recovery for companies, as well as for governing agencies.

Life cycle inventories of waste treatment activities are heavily dependent on the composition of the input waste, treatment technology, and the climatic conditions of the site. Several modelling options exist to generate waste-specific treatment datasets, but many have clear shortcomings related to either mass balance, flexibility, scientific robustness, reproducibility, or completeness.

At ecoinvent, we publish the ecoinvent database annually, which contains over 2,600 unique treatment datasets across wastes, technologies, and geographies. We continuously strive to improve our modelling and validation practices to provide our users with the most consistent, transparent, and complete background data for environmental assessments.

Therefore, we are developing a new suite of waste treatment models that provide complete transparency of input compositions, modelling parameters, and exchanges, with data sourced from and reviewed by several sectoral experts. The datasets maintain elemental mass balance, with comprehensive documentation of underlying assumptions and limitations. Emission ranges are validated with state-of-the-art literature and technologies.

With this presentation, we showcase the core methodological principles that govern our new modelling suite, such as balancing, property preservation, transparency, as well as fast and flexible inventory generation. As the current size of the waste sector indicates, there is a large demand for diverse, high-quality treatment datasets, which can only be maintained and achieved by these principles. The added value of the suite is highlighted by comparisons of activities generated for the current version of the database.

State of the Art Review: Investigation of various modelling strategies for chemicals in the field of synthetic resins

Sabrina Diniz, Jens Bachmann, Karina Kroos, Steffen Opitz

German Aerospace Center (DLR), Germany

Due to the large number of chemicals and the variety in their production pathways, there can be considerable gaps and associated uncertainties while conducting Life Cycle Assessments (LCA), especially during the phase of the life cycle inventory (LCI). In this regard, commercial databases and previous modelling approaches have focused on estimating values and proxies in the absence of specific industrial or confidential data. These methodologies are continuously developed and adapted in multiple approaches. However, a challenge that should not be neglected is the need for detailed and case-specific literature research and comprehensive knowledge of the chemical-technical field, which can lead to misunderstandings, errors and the exclusion of important information in the modelling phase, especially for practitioners unfamiliar with the subject. Despite various methodologies for modelling the LCI, especially for resin systems and their raw materials, there is no established and uniform framework for simplified modelling. In this research we want to show which methodologies are used to create these customised LCIs and what their similarities and differences are. It can be shown how conventional databases, like Ecoinvent or Cm.chemicals, and recent modelling approaches deal with data gaps. In addition to the common basis for these databases, it will be examined how new data sets can be developed independently with the help of databases in combination

with current modelling strategies in order to create a consistent yet comprehensive LCI. The results help to provide some insight into the overview and comparison of existing methodologies and draw attention to the associated uncertainties. This lays the foundation of providing a future framework to pursue a suitable and uniform modelling strategy in accordance with the existing databases. The overview carried out can support non-specialist LCA practitioners in particular to apply a suitable methodology when creating a detailed and holistic LCA for resin systems.

Harmonization of Global Automotive Material Information for Environmental Evaluation

Toru Furusawa, Tsuyoshi Ito, Yasunori Onaha

Honda R&D Co.,Ltd., Japan

In recent years, an environmental evaluation in the field of an automotive industry has been actively proceeding in order to realize circular design.

Automotive LCA practitioners usually evaluate GHG emissions using BOM (Bill of Materials) and IMDS (International Material Data Sheet) which consist of vehicle parts and composing materials. Among them, material information is complex and variable such as material process from mining, manufacturing to parts production which include recycled and bio-based materials, manufacturing technique, electricity and regionality effect. Accordingly, CFP calculation of material is quite difficult.

Although some commercial LCI databases are able to utilize to identify, data contents such as format, process information, data quality differs from each other across the world. Therefore, material carbon intensity and its LCI data settings are critical issues.

The purpose of this study is to develop a new material data management approach on LCA which is reliable, transparent, and easily available. In the end, it could enable environmental impact to reduce.

To solve the above issues, we proposed a material ID concept which enables material information to be traceable using a digitalized matching technique.

At first, we registered thousands of automotive material names which were used until now and the corresponding carbon intensity. Then, chemical composition data of CAS No. and VDA material code in IMDS were incorporated to a matching program code to identify material carbon intensity. Finally, tens of thousand lines of material information were converted from an uncertain disordered data in IMDS to a defined LCA material classification and the CFP calculation results were achieved.

It could be fruitful to discuss how to assess data reliability and a digital linkage from environment to social and economic value evaluation.

BONSAI: an Open-Source Platform for Product Footprinting

Stefano Merciai[1,2], Jannick Schmidt[1,3]

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BONSAI is an open-source platform designed to calculate the carbon footprint of products. Within this platform, a framework has been developed based on Input-Output Tables (IOTs) principles, tailored to meet the needs of the industrial ecology community. This framework is referred to as BONSAI-IO.

BONSAI-IO reconciles detailed physical technology information about production processes (bottom-up) with statistical data provided by official statistical offices or international institutions (top-down). APIs are utilized to collect data directly from source databases, while several production recipes have been sourced from existing scientific literature. The code that generates the database is written in Python and is freely

accessible on the GitLab repository. This ensures transparency and traceability of data.

The database is constructed using a modular approach. Each sector included in the database is modeled within a specific Python package, which can also be used independently of the BONSAI-IO workflow. Sectoral models may differ in terms of complexity, completeness, and other attributes. LCA practitioners are encouraged to contribute to the development by uploading their code to the repository. Git technology ensures transparency and accountability among contributors.

BONSAI-IO is a multilayer framework, meaning that flows are accounted for in various units such as tonnes, terajoules, euros, and more. Each unit corresponds to a distinct layer of the database. These layers are interconnected through properties of the flows, such as prices, calorific values, and other attributes. Each layer is balanced to ensure compliance with conservation laws.

The database can be used directly for calculating product footprints or as a background database. It covers all major global economies and five rest-of-world regions. Unlike conventional IOTs, BONSAI-IO incorporates the concept of markets (e.g. product markets or regional electricity mixes), which enhances the flexibility of the analytical tool, making it better suited to meet the requirements of scenario analyses.

BlueOn: a digital Marketplace pioneering transparent LCA data exchange for sustainable procurement

Bertrand Touzet, Antonin Falluel Morel

Eiffage, France

Today, all industries face mounting pressure to incorporate transparent environmental data into project delivery. Clients require detailed environmental impact assessments, while internal sustainability commitments, such as Science Based Targets initiative (SBTi) necessitate robust and transparent emissions tracking.

To do so, Eiffage has developed BlueOn, the first digital marketplace exclusively featuring products with specific LCAs provided directly by manufacturers. This innovative platform fosters collaboration between suppliers and buyers, addressing a critical gap in the current LCA landscape.

Currently, manufacturers invest significantly in LCA production yet struggle to effectively communicate this valuable information to buyers. BlueOn solves this challenge by providing a dedicated platform for manufacturers to showcase their products' environmental performance. The full digitalization of LCAs on BlueOn enables users to easily navigate with 3 dimensions: product specifications, pricing and environmental impacts. This unprecedented level of transparency empowers informed decision-making, driving the selection of low-impact materials and enabling accurate reporting for both projects and corporate sustainability goals.

BlueOn moves beyond traditional databases that often rely on outdated or aggregated data. By focusing on product-specific LCAs provided directly by manufacturers, BlueOn ensures data accuracy and comparability. This granular approach allows buyers to directly assess the embodied carbon and other environmental impacts of individual products, facilitating informed comparisons and promoting the integration of LCA data into procurement decisions and tendering processes.

This collaborative platform fosters a new level of transparency between suppliers and buyers, unlocking the full potential of LCA data to drive sustainable procurement. BlueOn empowers Eiffage, its clients, and its suppliers to make informed decisions and accelerate the transition to a lower-carbon future. By presenting environmental data with the same prominence as pricing, BlueOn transforms how environmental performance is evaluated and integrated into construction projects, ultimately facilitating the achievement of ambitious sustainability goals.

Emerging Technologies in European Research: Evaluating Data Collection Strategies for Life Cycle Assessments – A Case Study After 1.5 Years of the MULTIMOLD Project

Sarah-Jane Baur[1], Marina Proske[2], Nils Nissen[1], Sinem Döger[1]

[1]Fraunhofer IZM, Germany; [2]Umweltbundesamt, Germany

Introduction: LCA is crucial in identifying environmental hotspots in emerging technologies, but effective data collection remains a challenge, especially in early-stage R&D. This study evaluates the progress and effectiveness of data collection strategies for LCA in the MULTIMOLD project, after 1.5 years of implementation.

Methods: Over the course of the project, several strategies were deployed to enhance data collection and LCA practices, including early involvement in the development process, conducting screening LCAs to identify data gaps, engaging stakeholders for expertise and data sharing, and iteratively refining data as prototypes evolved. This evaluation assesses the success of these strategies based on the first LCA results and the lessons learned.

Results: The initial LCA results highlight key successes and challenges in the data collection process. Screening LCAs conducted early on allowed for more informed material and process selection, with several data gaps identified and addressed through stakeholder collaboration. While some data gaps persist, the iterative approach has led to improved data quality, particularly in the verification of industry-specific data. The involvement of stakeholders has been crucial in identifying proxy datasets and sharing industry insights.

Conclusions: After 1.5 years of project runtime, the evaluation shows significant progress in improving LCA data collection practices. Early-stage screening LCAs, stakeholder engagement, and iterative data collection have contributed to more robust sustainability assessments. Despite ongoing challenges in acquiring some data, these strategies have proven effective in enhancing the overall environmental performance of emerging technologies. The findings provide valuable insights for refining LCA methodologies and improving data collection in future research and development projects.

Advancing Life Cycle Assessment Through the Environmental Footprint (EF) Database

An De Schryver[1], Anna Ossolinska[2], Raoul Meys[2], Kiyotaka Tahara[3], Pieter Ravaglia[1], Jasper Scholten[4], Koichi Shobatake[5]

[1]PRé sustainability, The Netherlands; [2]Carbon Minds; [3]National Institute of Advanced Industrial Science and Technology (AIST); [4]Merieux NutriSciences / Blonk; [5]TCO2

The increased use of LCA in policy making asks for the need of a common database in Europe, easily accessible at reasonable price, broadly applicable and consistently developed using the same modelling rules. The Environmental Footprint (EF) Database project, launched in 2023 by the Directorate General Environment, tries to fulfill this need by developing robust and reliable datasets, compliant with the latest European Commission Environmental Footprint recommendations.

With a knowledgeable international consortium and through an open collaboration with industry stakeholders, the Environmental Footprint database project (also called “EF4.0”) is creating approximately 3300 EF-compliant “Core” datasets, available in fully disaggregated form and aligned with the required eILCD/ ILCD format. The datasets encompass a wide range of product categories and geographical regions, covering not only the European market but also global activities such as agricultural production, biomaterials and energy mixes.

The project timeline outlines a structured rollout with the initial discussions in 2024 on the upcoming modelling rules to be followed (to be inline with the newest EF recommendations), the first data set to be

completed throughout 2025, and the final datasets being delivered to the EC by mid 2026. Throughout this work, consortium members (and sub-contractors) collaborate closely with industry partners to ensure data quality and relevance, while addressing challenges like data confidentiality through broad averaging and strategic disaggregation.

This presentation will introduce the scope of the EF4.0 database project, outline the work done so far, and focus on the technical aspects to achieve the consistency and data quality required. By delivering high-quality, comprehensive data, the EF Database project will support a global shift towards more sustainable practices and informed environmental stewardship, making it a cornerstone in the evolution of LCA use in policy.

Data Collection and Management for LCA in Agriculture: Case Studies from Polish Cereal and Dairy Farms

Jolanta Baran

Silesian University of Technology, Poland

Agriculture plays a key role in global efforts toward sustainable development, while facing challenges such as greenhouse gas emissions, soil degradation, and limited water resources. Life Cycle Assessment (LCA) and Environmental Product Declarations (EPD) enable the quantification and communication of environmental impacts, yet the agricultural sector continues to struggle with data availability and quality issues.

This study focuses on strategies and tools for collecting, managing, and exchanging agricultural data, emphasizing their role in identifying key environmental "hotspots" (e.g., soil carbon sequestration, nitrous oxide emissions). The analysis also explores methods to improve the interoperability and transparency of background datasets used in LCA modeling for agricultural products such as wheat, and milk.

Additionally, the research includes case studies analyzing data collection from Polish farms producing cereals and milk. The findings aim to provide practical pathways for improving data quality and reliability, enabling sustainable decision-making at farm, regional, and global levels. The study also identifies areas for further work to enhance data systems in agriculture.

Session 3.08: Downscaling SDGs & Planetary Boundaries for Products & Organizations

Time: Friday, 12/Sept/2025: 11:30am - 1:00pm
Session Chair: Andreas Barth, Wood K Plus Kompetenzzentrum Holz GmbH, Austria
Session Chair: Massimo Collotta, Henkel AG & Co. KGaA, Germany

Downscaling the Doughnut: A Sufficiency-Based Approach for Sectoral Allocation within Planetary Boundaries

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The Planetary Boundaries (PB) framework defines safe ecological budgets, while the Doughnut framework integrates these budgets with minimum requirements for human well-being – Decent Living Standards (DLS). While these frameworks provide crucial guidance for framing absolute sustainability and addressing related challenges, their practical application at organizational and sectoral levels remain limited, particularly in developing equitable allocation schemes that balance social and environmental objectives. Existing methods allocate PBs to sectors using various ethical principles that inadequately account for functional diversity, which can lead to reproduction of (historical) injustices.

We propose a sufficiency-based allocation approach operationalizing the Doughnut framework globally. First, we define a universal "basket" of materials necessary to achieve DLS. Using Life Cycle Assessment, we quantify ecological impacts from provisioning this basket, establishing a global "base economy" meeting human needs.

Next, we evaluate if residual SJOS remains beyond the base economy. If surplus exists, we explore dynamic allocation strategies with the sufficiency-based allocation key and household expenditure data, across multiple pathways toward different sustainable futures. These pathways vary significantly in speed, ambition, and transformative potential to different scenario such as fossil-free society and widespread circular economy. Conversely, if no surplus exists or an ecological deficit emerges, our framework can help identify necessary trade-offs and targeted interventions, emphasizing demand-side managements and structural transformations to return within PB.

Our framework thus advances a globally coherent method for equitably allocating Earth's limited safe operating space, linking ecological limits with actionable pathways toward sustainability and social justice.

Downscaling national forest biodiversity indicators for sustainability reporting in forest-based industries

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Forest-based industries depend on wood as a raw material, but the extraction of wood impacts (in a negative or positive way) the state of forest biodiversity. As sustainability becomes increasingly important, companies try to measure impacts on biodiversity, driven by regulations such as the Corporate Sustainability Reporting Directive (CSRD).

Science-based indicators can help companies make informed biodiversity commitments. However, specific indicators for measuring and reporting biodiversity-related aspects remain scarce and are rather generic. Furthermore, biodiversity indicators are often designed at a global or national level, which creates a challen-

ge for companies who operate and make decisions at a site- or regional level. There is a growing need to downscale such national biodiversity indicators for application at the operational level.

In this context, we evaluate the applicability of established national forest biodiversity indicators (Forest Europe C1, C2, C4) for downscaling into corporate sustainability reporting. The goal is to enable companies from the forest based-industries to translate broad-level indicators into operationally meaningful metrics concerning sustainability reporting.

To assess the suitability of these indicators, we applied an Analytic Hierarchy Process (AHP) under involvement of experts from science, corporate sustainability management, NGOs, and forest and environment ministries. First results show that Protected forests, Diversity of tree species, Deadwood, Threatened Forest species and Age structure/diameter distribution are particularly suitable for application in sustainability reporting concerning forest biodiversity. In contrast, indicators such as Defoliation, Air pollutant deposition, Soil condition, Forest area used by the company, and Forest carbon were identified by the experts as less suitable.

Experts also noted practical challenges like costs, data availability, technical capacity, and limited biodiversity expertise in companies.

Our findings support the operationalization of biodiversity in corporate contexts and offer a blueprint for applying national biodiversity indicators at the company level, in line with CSRD requirements and broader conservation goals.

Science-based Targets and Strategic Pathways for a Sustainable Battery Industry

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Limiting global warming to 1.5°C requires urgent action across industries, especially for the electric vehicle battery industry, which risks shifting environmental burdens from the use stage towards raw material extraction and battery production. Current life cycle assessment (LCA) studies typically compare the environmental impacts from a relative sustainability perspective, i.e., identifying if one system has fewer impacts than another. However, such comparisons do not indicate if the impacts are within the planet's biophysical limits. Addressing this requires taking an absolute sustainability perspective, wherein product-specific science-based targets are derived and compared against environmental impacts.

We adopt an absolute perspective and derive targets for the battery industry from 2024 to 2050, based on the remaining carbon budget proposed by the IPCC to meet the 1.5°C target. We develop a prospective parametric LCA model to quantify the climate change impacts of battery production. We use the parametric model to develop marginal abatement cost curves (MACCs) and provide a strategic pathway to meet targets. The parametric model allows us to estimate changes in climate change impacts due to both foreground and background processes. In the foreground, factors such as the share of recycled materials, scrap rates, renewable energy usage, energy efficiency, specific energy improvements and logistics are considered. Meanwhile, in the background, variations due to different shared socio-economic pathways from the integrated assessment models are considered.

Finally, we compare the targets for the battery industry until 2050 with the estimated impacts and propose a strategic pathway for reaching them. This pathway includes a series of measures, selected based on the variance-based sensitivity analysis of the parametric model. The MACCs illustrate the reduction potential of the selected measures. Additionally, we present the net cost savings and expenditures associated with implementing these measures, thereby outlining a cost-effective, strategic pathway for a sustainable battery industry.

Calculating corporate carbon budgets based on human needs fulfilled by end-products

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To keep global temperature increase aligned with the Paris Agreement, significant reductions in global GHG emissions are needed. Absolute environmental sustainability assessments can evaluate the impact of human activities by comparing them to allocated shares of the remaining global carbon budget. At company level, the existing approaches used to determine such shares are mainly production-oriented, which encourages businesses to produce in a more eco-efficient way. However, these approaches do not consider the human needs of the consumer products that businesses contribute to fulfilling.

In this study, a new quantitative framework is developed to assess a company's absolute environmental sustainability based on its contribution to fulfilling consumer needs. The framework distinguishes between business-to-consumer (B2C) and business-to-business (B2B) companies. For B2C companies, the evaluation starts with a quantification of the needs fulfilled by the products they develop, as well as their climate impact, using LCA. The ratio, representing the impact per need fulfilled, is compared to emission limits derived from the literature, which give the impact trajectory needed for the product to stay within allowed climate budgets over time. For B2B companies, the assessment relies on the sustainability performance of the B2C companies that are downstream in their value chain.

The framework is applied to a case study and compared to existing approaches. For B2B companies, this new method implies that the same materials and products can have a different absolute environmental sustainability performance depending on which supply chain they are part of. This provides companies an opportunity to improve their performance by supporting supply chains with high potential to meet human needs. The consequences of such an approach to determine science-based targets and develop sustainability strategies at the company level are discussed. Challenges related to spatial and temporal resolution of impacts and the complexity of identifying end-use functions are also outlined.

Integrating Environmental and Social Impact Assessment using Conjoint Analysis: Case Studies of ICEVs, HEVs, and BEVs

Sayaka Kakiuchi[1], Kayo Murakami[2], Misa Iwamoto[3], Shutaro Takeda[3], Koichi Kuriyama[4], Norihiro Itsubo[1]

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In recent years, the integration of environmental and social impacts in life cycle assessment (LCA) has emerged as a critical theme in sustainability research. Notably, international initiatives such as the SDGs emphasize the growing need to assess environmental and social aspects within a unified framework. Conventional LCA has primarily focused on environmental impacts, but under initiatives led by UNEP, active efforts are underway to develop methods for evaluating social impacts and integrating them with environmental impacts. These efforts aim to provide a comprehensive understanding of sustainability across the entire product lifecycle. Various methods have been proposed for integrating environmental impacts, including single score approaches, trade-off analysis, and particularly, monetization techniques for environmental impact evaluation. In this study, we focused on LIME (Life-cycle Impact assessment Method based on Endpoint modeling), an integrated model developed in Japan. LIME3 employs conjoint analysis, enabling the evaluation of environmental service values as the willingness-to-pay (WTP) of people in G20 countries based on their individual values. Furthermore, we extended conjoint analysis to the evaluation of social impacts and integrated them with environmental impacts, offering a new framework for capturing trade-offs between environmental and social dimensions. Using the developed integration factors, we conducted an LCA of multiple vehicle types (ICEV, HEV, BEV) as a case study. The vehicle data, provided by several Ja-

panese automobile manufacturers, included a total of 15 vehicles. This study highlights the potential contribution of LCA to achieving sustainable development by integrating environmental and social factors in a unified assessment framework.

A critical analysis of carbon neutrality pathways and their sharing principles in the building sector

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The transition to net zero carbon emissions in the built environment remains a complex challenge. This paper critically examines the underlying value models that shape climate objectives within the building sector. Through analysing international, national and corporate decarbonisation roadmaps, targets, and pathways, we investigate intricate sharing principles that are rarely explicitly articulated but fundamentally drive systemic transformation. Our findings suggest that effective climate objectives in the building sector are predicated on adaptive sharing models that transparently discuss notions of responsibility and economic value. This research offers insights for policymakers, urban planners, and sustainability professionals seeking to develop nuanced approaches to achieving net zero objectives in the built environment.

Session 3.09: Tackling climate risks and nature dependencies for a healthy future

Time: Friday, 12/Sept/2025: 11:30am - 1:00pm
Session Chair: Gian Andrea Blengini, University of Turin, Italy
Session Chair: Giulia Maggiora, Quantis, Italy

Impact of climate change-driven wildfires on the biogenic carbon of Pinus Pinaster Forest in Portugal

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In the civil engineering industry, wood-based materials have become very popular, and they have been marketed as a solution for the decarbonisation of this sector. However, the lack of standardisation to account for biogenic carbon and the non-consideration of the effects of climate change could facilitate the manipulation of results and not reflect on the reality of the forestry sector. In the case of Portugal, the long history of intense wildfires has contributed significantly to the carbon emissions yearly. In addition, with climate change intensifying this issue, using wood-based materials in Portugal may raise valid concerns. Striking the right balance between the undeniable benefits of wood as a renewable resource and the challenges posed by climate-related factors is crucial for sustainable building in fire-prone regions.

In this context, the main goal of this study is to show the importance of climate change's effects on the sustainability of Portugal's Wood industries. Since most wood materials for the construction sector in Portugal are derived from the Pinus Pinaster, also known as Maritime pine, the main focus of this paper will be on this type of forest. The methodology will consider the historical carbon dynamic of the Pinus pinaster forest in Portugal, using the IPCC 2006 Guideline for National Greenhouse Gas Inventories, chapter 6 (Land use, land use change, and forestry). The future scenarios for the next 30 years will be derived from the historical data for fire emissions and harvesting wood production. Three scenarios will be created: Optimistic (reduction of the emissions), Neutral (keeping the average emission constant through the years), and Pessimistic (following the historical increased tendency of emissions). As a result, we will evaluate the current biogenic capacity of Portuguese Pinus Pinaster forests and quantify the impact of wildfires on the sustainability of this forest.

Using regional environmental limits for biosphere integrity to inform life cycle assessments of building materials

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Anthropogenic pollution and resource use have led to a rapid decline in biodiversity and greatly impacted the integrity of the biosphere. To ensure that our efforts to halt the rapid decline are effective, we need to move beyond assessing whether one activity performs better than the other; we need to assess whether the activity respects the Earth´s environmental limits. The absolute environmental sustainability assessment (AESA) approach was developed to appraise whether an activity is sustainable in absolute terms. In AESA, environmental impact scores calculated using the Life Cycle Assessment (LCA) method are evaluated against environmental limits. Impacts on the biosphere integrity have global and local effects. In most

AESAs, global limits, such as planetary boundaries, have been applied. Regionalized AESAs require LCAs, that involve a regionalized life cycle inventory (LCI) linked to set of regionalized characterization factors (CF).

The aim of this study is to make regionalized LCI for a set of buildings materials and link the regionalized LCIs with regionalized characterizations factors to determine how important regionalization is and to provide the first step of a regionalized AESA. The sensitivity of the impact scores of the building materials towards changing the degree of regionalization of the different elementary flows is tested. Further, it is investigated whether the choice of the LCIA method could be influential in what building material appears to have the lower impacts on biosphere integrity. Preliminary results indicate that the ranking of the building materials, based on their ecosystem quality score, is sensitive to the choice of LCIA method and level of regionalization. The regionalized LCAs of this study can inform AESAs with regionalized environmental limits. Further it provides information about which supply chain data that is most crucial to collect

The role of Hull Coatings in Sustainable Shipping: Decarbonization and Marine Ecosystems

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The marine industry is responsible for 3% of total carbon emissions and has embarked on a decarbonization journey driven by regulators, market forces, and a sense of responsibility. However, the focus on climate change creates a tunnel vision where other environmental impacts are overlooked.

Hull coatings are a recognized solution for lowering carbon emissions from shipping. They prevent the accumulation of fouling and create low roughness surfaces that enable a smoother navigation and minimise fuel consumption. Advanced solutions enable double-digit efficiency improvements and are regarded as a key mechanism to drive decarbonisation in the marine industry.

However, traditional coatings rely on chemical biocides and polishing technology to remove fouling. Even though the use of biocides is strongly regulated from a risk assessment perspective, potential toxicity impacts of biocide emissions are often not considered from a sustainability standpoint. Alternative fouling defense coating technologies rely on a lower biocide content and limited emissions into water, and are therefore able to deliver optimized fuel performance and reduce the impact on marine ecosystems.

Currently there is still a lack of understanding about the tradeoffs between emissions to air and to water, and most of the common biocides used in hull coatings have not been characterized yet. We are developing toxicity characterisation factors based on USEtox model for the main emitted substances, and are integrating these in the sustainability evaluation and value proposition of hull coating solutions.

This presentation will present the state of the art in the characterisation of biocide emissions from hull coatings, and demonstrate the sustainability advantage of advanced technologies versus traditional solutions. We will guide the audience through the business case of hull coatings and will discuss the non-compensatory nature of different environmental impacts to promote sustainable decision making.

Assessing Corporate Commitment to Biodiversity and Ecosystem Services: A Text Mining Approach with publicly available sustainability reports

Sun-Hea Hong

University of Stuttgart, Germany

In light of increasing environmental concerns, this innovative review study investigates the extent to which companies integrate biodiversity, land use impacts, and ecosystem services into their sustainability reporting. Utilising text mining techniques, this study analyses sustainability reports from a diverse range of industry stakeholders, including approximately 230 members of the Business for Nature coalition, 500 adopters of the Taskforce on Nature-related Financial Disclosures (TNFD), a databank of 290 reports from the World Business Council for Sustainable Development (WBCSD), and an additional 200 sustainability reports identified through Google searches.

The research starts from a primary question: do companies consider biodiversity, land use impacts, and ecosystem services in their reporting beyond greenhouse gas emissions? If so, how do they assess these factors, and what indicators are utilized and correlated? We first determine whether the reports tackle these themes, followed by the identification of assessment methodologies employed, drawing from Natural Capital Accounting (NCA) and Life Cycle Assessment (LCA). Additionally, we deep dive to uncover potential correlations between NCA and LCA methods, indicators, and specific parameters.

The study contributes valuable insights into the current state of corporate sustainability reporting practices, highlighting areas for improvement in strategies to align with sustainability goals. By identifying gaps and underrepresented areas, we emphasize the need for companies to adopt a more holistic approach in their reporting, ensuring that all ecosystem services are adequately addressed.

Preliminary findings suggest that provisioning ecosystem services, such as timber and crop production, are prioritized in corporate reporting, while regulating services like erosion control and pollination are underrepresented. The underrepresentation of regulating services like erosion control and pollination suggests a disproportionate focus that underscores the need for a more comprehensive assessment.

Leveraging Climate Change Mitigation From Harvested Wood Products in the Built Environment

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Harvested Wood Products (HWP) are increasingly being promoted by national policy makers, industry representatives and academics as an effective approach to decarbonise the built environment. HWPs lock up sequestered biogenic carbon out of the atmosphere for extended periods of time, and can substitute carbon intensive construction materials such as steel and concrete. To facilitate actionable policy making for decarbonisation of the European Union (EU) built environment, this study investigates future oriented scenarios relating to HWP biogenic carbon storage and associated HWP material substitution through prospective Life Cycle Assessment (LCA). Future oriented scenarios were designed to represent a range of possible value chain configurations and decarbonisation contexts. Value chain configurations start with "business as usual", then integrate varying combinations of HWP carbon storage and bioenergy generation, with shorter or longer (cascading) value chains, with and without debated permanent storage options such as landfilling or Bioenergy, Carbon, Capture and Storage (BECCS). Decarbonisation contexts explore different rates of material and energy decarbonisation out to 2100, to understand the impact of diminishing greenhouse gas (GHG) substitution benefits through time on the net climate performance of HWP value chains (including upstream forestry dynamics). Results from this study provide insight to policy makers on how HWP deployment can facilitate the transition towards a net-zero built environment whilst also leveraging climate mitigation benefits across the land and energy sectors.

Toward Climate-Resilient Agriculture: A Life Cycle Assessment of MDF and Poplar Biochar for Soil Health and Carbon Sequestration

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Now that the year 2024 is officially the warmest year on record, with a global average surface temperature of 1.55°C above the pre-industrial level, the necessity to mitigate carbon emissions has become more imperative now than it has ever been (WMO, 2025). The increasing temperatures bring forth a wide range of impacts such as droughts, floods, biodiversity loss and more impacting all sectors of society, including the agricultural industry (European Commission, n.d.; Milman, 2022; Schmitt et al., 2022). In order to put a halt to anthropogenic induced climate change, the Intergovernmental Panel on Climate Change (IPCC) has indicated the prerequisite of including carbon dioxide removal (CDR) technologies to stay in line with the 1.5°C-consistent pathways (IPCC, 2022). One of these recognised CDR technologies is biochar, a product formed through the thermochemical conversion of biomass in an oxygen-limited environment, a process also known as pyrolysis (Lehmann & Joseph, 2024). The implementation of biochar in soil systems hails a wide range of additional benefits including crop yield, water retention, nutrient retention and more (Calvin et al., 2023; Joseph et al., 2021; Muñoz et al., 2017). The proposed study delves deeper in the comparison of two biochar feedstocks, namely medium density fibreboard (MDF) and poplar wood chips, as the environmental impacts associated with their sourcing and processing into biochar-to-agriculture systems are quantified and evaluated in a Life Cycle Assessment (LCA). The research investigates the environmental impacts and addresses the handling of biogenic carbon. Furthermore, the study incorporates new experimental data from the Flemish C-Farms project looking beyond carbon sequestration, delving deeper into other co-benefits. A cradle-to-grave LCA is performed in accordance with ISO guidelines.

Session 3.10: LCM in Rail, Aviation and other transport systems

Time: Friday, 12/Sept/2025: 11:30am - 1:00pm
Session Chair: Davide Bonaffini, Hitachi Rail, Italy
Session Chair: Ladji Tikana, International Copper Association, Germany

A full sector aiming for integration of LCA results into daily-life design and strategy decisions: Developing a LCA – eco-design tool for the European aerospace sector

Karin Treyer[1], Marnix Verkammen[2]

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Satellites orbiting Earth provide a wide range of services to our daily life, science, and governments. The number of satellites sent up by launchers is expected to increase heavily in the coming decade. However, the environmental impacts of emitting an increased amount of (unknown) substances into various atmospheric layers remain largely unexplored. Moreover, LCA is not yet integrated into the European space sector, despite decision-makers and engineers expressing interest in using LCA results to guide their actions.

This presentation will be around the "Assessment and Comparison Tool (ACT)", currently being developed by a consortium funded and initiated by the European Space Agency (ESA). ACT is designed for engineers and LCA practitioners in the aerospace sector to calculate environmental impacts of current&future launchers, satellites, or entire space missions. Additionally, ACT will support decision-making during early project phases by integrating space-specific models and data, such as a trajectory optimization model, an atmospheric emission model, or orbital space debris information, while extending the LCA methodology. Non-LCA-experienced ACT users will be guided through data entry. A special emphasis is placed on the visualization of results to facilitate their interpretation and lead to eco-design actions.

The unique aspect of ACT is its development amidst close collaboration activities of diverse stakeholders across the European space sector, all working together to better understand the environmental impacts of human activities related to space. This sectorial-wide collaboration presents challenges, such as finding common terminology and understanding, or finding solutions for methodological gaps. But it also offers the chance to embed life-cycle thinking into daily work practices. The presentation will detail ongoing initiatives in the space sector right now, and how they are connected to ACT.

Can hybrid-electric aviation clear the sky for sustainable air travel?

Shan Zhang[1], Rickard Arvidsson[1], Anders Nordelöf[1,2]

[1]Chalmers University of Technology, Sweden; [2]Swedish National Road and Transport Research Institute, VTI

Aviation contributes approximately 2–3% of global greenhouse gas emissions, and this share is expected to grow as aviation remains the fastest-growing transport sector, with annual traffic projected to increase steadily until 2050. The International Civil Aviation Organization has set a target for achieving net-zero carbon emissions from aviation globally by 2050. Electrification of airplanes has emerged as a promising strategy, attracting significant attention from both industry and academia. This study assesses the potential future environmental performance of a hybrid-electric airplane, modeled on an industrial design proposal provided by a company manufacturing the airplane. A prospective life cycle assessment was performed for the years 2030, 2040, and 2050. A functional unit of one passenger-kilometer is considered and the system boundary is from cradle to grave. The model accounts for key factors influencing airplane production and its use

phase, including motor design, power source, battery performance, and flight profile. It also incorporates potential changes in critical background sectors (such as steel production, fuel supply, and electricity generation) under different future scenarios. The results provide insights into the environmental performance of hybrid-electric aviation relative to conventional combustion-based aviation, identify environmental hotspots within the product system, and highlight areas with notable potential for impact reduction. Preliminary findings suggest that hybrid-electric aviation could reduce environmental impacts considerably compared to conventional aviation. Sensitivity analyses indicate that technology-related parameters have the greatest influence on the uncertainty of the results. These findings offer valuable insights into the environmental implications of electric aviation and can serve as a foundation for enhancing the design and sustainability of future electric airplanes.

Life Cycle Assessment of Aircraft Dismantling: A Path to Sustainable Aviation Practices?

Benjamine Belloncle, Talon Olivier

Materia Nova, Belgium

The aviation industry is a critical sector in the global economy, contributing significantly to transportation and trade. However, it also accounts for a notable portion of global carbon emissions and waste generation. As aircraft approach the end of their service life, the dismantling process becomes a pivotal point for mitigating environmental impact. Aircraft dismantling involves the decommissioning, recycling, and disposal of parts, often resulting in significant waste and resource consumption. While much attention has been given to the environmental impacts of aircraft operations, the dismantling phase is less explored despite its potential for reducing the industry's overall ecological footprint.

This contribution will present LCA applied to aircraft dismantling, aiming to quantify and compare the environmental impacts of current practices and identify opportunities for improvement. Specifically, it addresses energy consumption, waste generation, emissions, and material recovery rates within different dismantling methodologies. Through a case study of current development of aircraft dismantling facilities within the PLANUM project, this research evaluates the trade-offs between traditional methods and emerging technologies that prioritize resource efficiency and circular economy principles.

The findings of this study reveal that by improving recycling and reuse rates, and implementing more energy-efficient practices, aircraft dismantling can play a crucial role in the broader effort to obtain significant reductions in the carbon footprint, material waste, and energy consumption can be achieved through the adoption of more sustainable dismantling techniques.

Advancing Circular Manufacturing for Sustainable Rail Traction Components - An integrated LCA and Circularity Tool."

Zienab Elghoul[1], Aska Fontanez[1], Antoine Juge[1], Clément Maussion[3], Thomas Pohl[2], Tabea Nydegger[2], Deba Prakash Guru[3], Lorenzo Benedetti[1]

[1]Eurotube Foundation; [2]Ostschweizer Fachhochschule; [3]Alstom Transport

The railway sector accounts for only 2% of CO_2 emissions in the mobility sector while delivering 7% of global passenger transport, highlighting its role in the low-carbon transition. However, the rail industry's substantial reliance on primary resources, particularly metals, is subject to mounting pressure to minimise its environmental impact, reduce resource use, and address challenges in the metals value chain, including supply risks and resource constraints. It is, therefore, vital that circular approaches are adopted to ensure sustainable growth in the rail transport sector.

The inherent complexity of rail systems, characterised by multiple subsystems and a dynamic value chain,

poses significant challenges in implementing unified strategies to enhance environmental impact and circularity. A bottom-up approach is imperative to address these challenges.

The "R2TraC—Recycling and Reuse of Traction Components" project, a collaboration between EuroTube, Alstom Transport, and Fachhochschule OST, aims to address the challenges of implementing circular economy principles in the rail sector. The project introduces a framework that enables stakeholders in the value chain to integrate circularity and environmental metrics into their operations for traction components. The framework's core is a parameterised Life Cycle Assessment (LCA) and Circularity assessment tool. This tool evaluates environmental, technical, and circularity indicators, supporting the development of circular strategies while meeting high-performance standards.

The novelty of this framework lies in its ability to integrate sustainability assessments into the design workflow, particularly during post-market design iterations, a feature absent in traditional methodologies where such evaluations are typically conducted only after the design process is complete. This integration offers design engineers actionable insights and facilitates iterative evaluations, thereby transforming component design and manufacturing processes. The framework under discussion is poised to usher in a new paradigm in sustainable engineering.

Fuel Production and Transport Chain for Aviation – an Environmental and Economic Comparison of LH2, SAF and Fossil Kerosene

Kai Mönnich, Veatriki Papantoni, Rahul Ramesh Nair, Urte Brand-Daniels

German Aerospace Center, Institute of Networked Energy Systems, Germany

The aviation sector contributes significantly to global warming while being expected to grow further. To reduce the climate impact, new sustainable energy carriers are needed. The BMWK funded project ZEexplore considers for the first time life cycle assessment (LCA) and techno-economic analysis (TEA) methods of both the fuel production & transport supply chain and for flight operation directly in the pre-design phase of an aircraft, together with an aircraft manufacturer. Target year of the study is 2035, the possible roll-out date of the aircraft. This contribution focus on the underlying fuel supply chain.

We applied prospective LCA and TEA to compare the production & transport of liquid hydrogen (LH2), synthetic aviation fuel (SAF) and fossil kerosene. The production of these new energy carriers is based on water electrolysis using electricity from on- and offshore wind energy and utility PV. For LH2 synthesis the next step within the supply chain is the liquefaction process, while for SAF is produced from direct air capturing (DAC) coupled with a Fischer-Tropsch process. The consideration of pipeline and truck transport completes the assessment of the environmental impacts and costs. Moreover, we analysed different technologies within the supply chain as AEL and SOEL electrolysis, and different electricity generation scenarios, e.g. offshore wind energy and an expected 2035 EU-mix of wind and solar PV.

Our contribution not only addresses the question of the best production pathway but also analyses different transport routes utilizing a sensitivity study. We show the optimal combinations that will lead to lowest environmental impacts while at the same time taking its costs into account to ensure economic competitiveness. We also highlight the impact of different electricity generation scenarios on environment and economics, and by consideration of different future technology scenarios we assess the range of potential future costs and environmental impacts.

Environmental Impacts of Shipping Energy Transition: Insights from an Integrated Energy System and Life Cycle Assessment Model.

Fayas Malik Kanchiralla[1], Selma Brynolf[1], Maria Grahn[1], Julia Hansson[2]

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Shipping is considered a 'hard to abate' sector, facing increasing pressure to reduce greenhouse gas emissions. Multiple policy tools are under consideration by the International Maritime Organization to achieve GHG emission reduction targets. The influence of different policies on the shipping sector's energy and fuel transition is uncertain, as it is affected by energy supply and demand from other sectors. This study explores cost-optimal pathways under various policies, accounting for energy supply and demand interactions from other sectors using a global energy system model. The study analyzes the environmental impacts associated with these energy transition scenarios by integrating prospective life cycle assessment with the energy system model. In most policy scenarios, ammonia emerged as the most effective solution for the shipping energy transition. However, this shift increases environmental impacts such as eutrophication and acidification, linked to ammonia leakages and emissions of nitrogen oxides and nitrous oxides from engines. Until 2070, the transition also brings other trade-offs, including increased land use, water depletion, and mineral resource impacts, primarily because ammonia supply comes from blue hydrogen and bio-hydrogen during this period. The results highlight the need for electro-hydrogen and renewable energy supply due to their lower environmental impact. For short-route shipping segments, battery electric options emerge as the most cost-effective solution, significantly reducing well-to-wake climate impact and other environmental impacts like particulate matter, eutrophication, acidification, and fossil resource use. Nevertheless, achieving a just and sustainable transition requires further research into the social, ethical, and environmental consequences of renewable energy imports, alongside strategies to mitigate burden-shifting.

Decarbonizing Maritime Shipping Through Multi-Fuel Solid Oxide Fuel Cell Pathways: Synergies and Trade-offs Between Environmental and Social Sustainability Metrics

Alena Frehner, René Itten, Matthias Stucki

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With the maritime shipping industry being responsible for the emission of about 2.5% of global greenhouse gas (GHG) emissions, decarbonising this sector has become a key regulatory target on the European as well as global level. A solution for a more sustainable operation of maritime vessels is proposed by the Horizon Europe project FuelSOME, which pursues the central goal of reducing the GHG emissions of the shipping sector by 50% until 2050. The approach of the project is to develop a multi-fuel capable propulsion system based on Solid Oxide Fuel Cell (SOFC) technology for maritime shipping. The envisioned fuel cell-based propulsion system is to be operated on ammonia, methanol and hydrogen. Regarding these fuels, short- and long-term sustainable supply chains are explored, and their life cycle sustainability impacts are explored.

In cooperation with project partners, foreground data on the life cycle of the multi-fuel energy generation system was used to perform a cradle-to-grave life cycle sustainability assessment (LCSA). With a focus on e-fuels from different electricity sources, the environmental and social impacts of a maritime vessel operated on ammonia, methanol and hydrogen were assessed, using a comprehensive set of indicators. The outcomes were compared to a reference case of a fossil-fuel powered vessel, which allows for a discussion of synergies and trade-offs.

Overall, certain scenarios and processes were identified as hotspots regarding environmental as well as social impacts. The fuel production was found to be the primary contributor to a majority of environmental and social impact categories. It was further found that a vessel powered by the proposed SOFC system must be operated on hydrogen produced from hydro or wind power, to reach the overarching decarbonisa-

tion goal.

Integrating BIM and LCA for sustainable high-Speed rail infrastructure: A framework for early design stage environmental assessment

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The building and infrastructure sectors have a substantial impact on the global environment, underscoring the critical necessity for sustainable design practices. This study focuses on the integration of Building Information Modeling (BIM) and Life Cycle Assessment (LCA) to evaluate the environmental impacts of high-speed rail infrastructure projects from the initial design phases, by coupling BIM's data-filled 3D modeling with LCA's systematic evaluation of environmental impacts.

The objective is to enhance interoperability between BIM and LCA tools in order to optimize design and reduce environmental impacts throughout the infrastructure's life cycle.

We propose a methodological framework that involves thorough data collection from railway projects, covering design specifics, material specifications, and maintenance needs. An updated BIM-LCA integration framework has been developed using Ecoinvent 3.9.1 for comprehensive and accurate life cycle inventory data. Environmental indicators such as carbon footprint, energy consumption and waste generation are calculated using OpenLCA, allowing real-time feedback on performance.

Sensitivity analyses have also been carried out to identify key design and operational factors influencing the environmental results.

Preliminary results from a high-speed rail bridge case study indicate that both the production and maintenance stages alone contribute between 93% and 99% of the impacts: water consumption, land use, freshwater ecotoxicity, human toxicity, marine ecotoxicity and mineral resource scarcity.

A major portion of these impacts was linked to the production of concrete components, such as piles, beams. These initial findings highlight the significance of material selection in railway infrastructure projects to minimize environmental impacts and advance sustainable practices in the construction industry.

This study offers insights into the potential of integrated BIM-LCA methodologies for fostering sustainable infrastructure design. This approach promotes informed decision-making by allowing for real-time evaluation of environmental performance and enhancing data exchange within the BIM and LCA workflow.

Environmental Impacts of Global Rail and Road Freight Transport Under Prospective Scenarios

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More than 6% of global carbon dioxide emissions are caused by freight transport by road, dominating the overall emissions from the freight transport sector. To keep climate targets within reach, a rapid decarbonization of the sector is necessary, while holistically considering trade-offs with other environmental impacts. Drastic emission intensity reduction is indispensable to reduce sector-wide emissions, as global freight transport demand is projected to almost double by 2050. Therefore, not only should new technologies and efficiency improvements of road freight transport be considered, but also the land-based alternative of rail freight transport. This study assess the environmental impact profile of alternative prospective scenarios

for the freight transport fleet considering both rail and road transport until 2050, using prospective Life Cycle Assessment (pLCA). To do so, the premise Python library for conducting pLCA, is augmented to integrate freight transport scenarios from the Integrated Assessment Model (IAM) REMIND. The Life Cycle Impact Assessment (LCIA) is performed in ActivityBrowser (AB) using the impact assessment method Environmental Footprint (EF) v3.1. The assessed scenario space includes all available REMIND Shared Socioeconomic Pathways 2 (SSP2) scenarios from a business-as-usual scenario (SSP2-Base) to a scenario limiting global warming to 1.5 degrees (SSP2-PkBudg500). Results show that climate change impacts from rail freight transport are only 10-25% of those from road freight. Similar results can be observed across all other impact categories where rail freight transport shows significantly lower results compared to road freight transport, due to the higher energy and material efficiencies of trains. Sector-wide climate change impacts can be reduced by up to 37% with a higher share of freight transport by rail, decreased absolute freight transport growth, decarbonization of the energy supply and increased electrification of the vehicle fleets, although the latter increases most impact category results if applied to lorries.

Session 3.11: Ecotox/Toxicity Metrics for Portfolio Assessment in Chemicals

Time: Friday, 12/Sept/2025: 11:30am - 1:00pm
Session Chair: Tomas Vilhelm Rydberg, IVL Swedish Environmental Research Institute, Sweden
Session Chair: Peter Rudolf Hans Saling, BASF SE, Germany

Toxicity assessment in industrial chemicals management: A Safe and Sustainable-by-Design Case Study on Electronic Components and Electric Vehicle Parts containing Phosphinate Flame Retardants

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As part of the European Green Deal, the EU Commission published the Chemicals Strategy for Sustainability in 2020. One of the aspects is the proposal for the assessment of new chemicals using the Safe and Sustainable-by-Design (SSbD) framework, which was developed by the EU Joint Research Center (JRC). To validate the applicability of the framework several case studies were conducted. One of these focused on flame retardants for electronic components and electric vehicle parts.

To assess the environmental performance of electronic components and electric vehicle parts a comparative LCA was conducted. The LCA compares systems using phosphinate-based flame retardants containing diethylphosphinic acid aluminium salt (DEPAL) with those using brominated flame retardants. In addition, the potential health impact on workers in production and processing stage was estimated with the tool ProScale. To investigate potential toxicological effects in case of accidental fires, the release of toxic components in the smoke was investigated.

The resultant SSbD scores based on the LCA show that the products using DEPAL have lower environmental impacts than the ones using halogenated flame retardants, particularly regarding toxicity, climate change, pollution and resources. The scores for toxicity, climate change, and pollution for DEPAL-based products show good improvements (score =2). For resources, the improvements are very good mainly due to the avoidance of antimony (score=3).

The ProScale study showed that the products based on brominated polystyrene and melamine cyanurate have higher toxicity scores compared to DEPAL-based recipe. Moreover, the fire tests reveal that products containing halogenated flame retardants tend to increase the toxicity of smoke compared to DEPAL-based alternatives.

In conclusion, the SSbD framework was applied for the comparative environmental assessment, along with toxicity and accidental fire studies. The effort involved to apply the framework is comparatively high and requires very good data, especially for products that are still under development.

Integration of Risk Assessment and Life Cycle Assessment in the Context of Safe and Sustainable by Design Era

Martina Menegaldo[1], Tomas Rydberg[2], Stathis Reppas[2], Maria Rachele Sesterzi[1], Rosella Telaretti Leggieri[2], Alessandra Fiorucci[3], Pernilla Andersson[2], Håkan Stripple[2], Anna-Karin Hellström[4], Emma Strömberg[2], Elisa Giubilato[5], Danail Hristozov[5], Alex Zabeo[5], Lisa Pizzol[5], Elena Semenzin[1]

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The integration of Risk Assessment (RA) and Life Cycle Assessment (LCA) to evaluate impacts on human health and the environment has been a long-discussed topic. With the introduction of the Safe and Sustainable by Design (SSbD) framework, this integration is becoming more urgent. The SSbD framework, developed to support the Chemical Strategy for Sustainability goals, aims to reduce the use of hazardous substances and minimize environmental impacts. It includes five iterative steps, with the first three focusing on safety (hazard and exposure assessment in the production and use phases) and the last two addressing sustainability (environmental, social, and economic performance through LCA). The testing phase for the SSbD framework has revealed challenges in conducting parallel evaluations of safety and sustainability. Key issues include the lack of clear data requirements, the ambiguity in integrating RA and LCA methodologies, and the need for consistent communication of results to avoid misinterpretation. These challenges are particularly relevant in the context of emerging regulatory frameworks like the Ecodesign for Sustainability Product Regulation (ESPR) and the Digital Product Passport (DPP), which will require transparent, harmonized data and communication. This study investigates differences in human toxicity indicators between USEtox and ProScale methods, focusing on how the grouping of chemicals, based on effect factors, impacts the estimation of potential risks. A case study demonstrates how varying classification approaches, such as USEtox's division into carcinogenic and non-carcinogenic groups and ProScale's five-category system aligned with the CLP Regulation, affect life cycle risk assessment outcomes. Additionally, these groupings are compared with the classification proposed in the SSbD framework. The study highlights the complementary roles of RA and LCA within the SSbD approach, providing insights into portfolio assessment relevant to the chemical industry and emphasizing the need for clearer definitions of system boundaries, improved data integration, and effective communication of uncertainty.

Job creation and occupational human toxicity in LCSA of recycled PVC for the construction sector

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PVC is widely used in pipes, window frames and other building elements, with an estimated 70% of the PVC produced ending up in the construction sector. A relevant but less studied pillar of LCSA of (recycled) PVC is the social one. This study aims to assess the potential social impacts of the life cycle of recycled versus virgin PVC window frames, as a complementary assessment to an existing environmental LCA of this case study. Foreground system of linear scenarios covered PVC and profile production, window assembly, use, disassembly, collection and incineration. In addition to these processes, circular scenarios include reuse and mechanical recycling. For inventory and impact phases, a key parameter in the analysis of the social pillar is worker hours. Data on worker hours are typically derived from input-output databases and regional sectoral statistics. Due to aggregation of data by sector in such databases, values for worker hours for specific processes are rough estimates. To address this, we collected sector- and process-specific worker hours for the foreground system. Then we focused on two related indicators: job creation and occupational human toxicity. To assess toxicity, we collected worker hours for specific processes as they relate with

worker exposure to substances, using the Pro-Scale methodology. Results show human toxicity potential per unit process. Results concerning job creation show which processes in the foreground system are the most labour intensive, for example manual processes for installing frames require more worker hours than industrial processes. A comparison of the results is shown using sector- and process-specific worker hours. Worker hours vary according to technology used, level of automation and scale of production. When including the background system, the study is limited to the sectoral worker hours as the methods developed so far contain this type of data only.

Addressing Eco-toxicity impacts in LCA approaches with the new ProScale E approach for chemicals

Peter Rudolf Hans Saling[1], Martin Klatt[1], Hannah Wagner[1], Richard van Gelder[1], Massimo Collotta[2]

[1]BASF SE, Germany; [2]Henkel AG & Co. KGaA

The ProScale E approach offers significant benefits in addressing eco-toxicity impacts within Life Cycle Assessment (LCA) approaches for chemicals in different applications, e.g. for chemicals used in the building and construction sector.

The assessment of eco-toxicity for chemicals within a Life Cycle Assessment (LCA) framework is crucial for understanding the environmental impacts of chemical products, especially in the building and construction sector. The new ProScale E methodology offers a comprehensive approach to evaluate eco-toxicity by integrating advanced metrics and product information. This new method enhances the accuracy and reliability of eco-toxicity assessments by considering various environmental compartments and exposure pathways. ProScale E facilitates the identification of potential ecological risks associated with chemical use and supports the development of safer and more sustainable chemical products. By leveraging ProScale E, stakeholders can make informed decisions to minimize the ecological footprint of chemicals throughout their life cycle. Additionally, ProScale E integrates well-established data systems from REACH and MSDS, further enhancing its robustness and applicability. The approach also benefits from easily available data derived from risk assessments, making it a practical and efficient method for industry transformation and promoting sustainable practices in the chemical industry. In the presentation, examples are integrated as well, showing how ProScale E can be applied and how it delivers meaningful results inline with risk assessment results of materials. The use of ProScale E in the Product Environmental Footprint methodology, as well as in ESPR and SSbD, is possible and enables a harmonized approach to identify more sustainable solutions, supports the transformation of industry and supports decision-makers to identify improvement potentials together with holistic results derived from LCA.

A Safe and Sustainable-by-Design (SSbD) Approach Rooted in Multiobjective Optimization: Case Study on Bioplastics and Fossil Plastics

Akshat Sudheshwar, Kealie Vogel, Claudia Som, Roland Hischier, Bernd Nowack

Empa – Swiss Federal Laboratories for Material Science and Technology, Technology and Society Laboratory, Lerchenfeldstrasse 5, 9014 St. Gallen, Switzerland

This study proposes treating Safe and Sustainable-by-Design (SSbD) as a Multiobjective Optimization Problem (MOOP). The MOOP framework for SSbD facilitates the simultaneous optimization of multiple, often conflicting objectives, such as balancing environmental safety and sustainability. The approach is applied to lifecycle scenarios of commonly used plastics—PET, HDPE, LDPE, PA, PU, and PLA. Sustainability metrics over each lifecycle scenario are evaluated using the Environmental Footprint (EF) method to compute lifecycle impacts. In contrast, the safety metric is based on risk assessments addressing hazards and occupational, human, and environmental risks associated with each lifecycle scenario. Additionally, functionality, defined by the intended applications in the lifecycle scenarios, is included as a third metric. By plotting

these metrics across all possible lifecycle scenarios, the MOOP approach identifies optimal SSbD lifecycles for each plastic-type and also provides a detailed understanding of trade-offs, particularly between functionality and End-of-Life considerations for both fossil- and bio-based plastics.

Session 3.12: LCSA advancements and implementation in building Part II

Time: Friday, 12/Sept/2025: 11:30am - 1:00pm
Session Chair: Matthias Fischer, Fraunhofer Institute for Building Physics IBP, Germany
Session Chair: Pamela Maria Haverkamp, INaB - RWTH Aachen, Germany

Integrating Construction KPI Data with Life Cycle Assessment: A Case Study of the UCL New Student Centre

Daniel Anyanya[1], Charnett Chau[1], Silvia Fiorini[2], Andrea Paulillo[1], Paola Lettieri[1]

[1]UCL, United Kingdom; [2]Mace Group Ltd., United Kingdom

The construction sector is a significant contributor to global environmental challenges, accounting for nearly 40% of global energy consumption and greenhouse gas emissions. This study investigates the environmental performance of University College London (UCL) New Student Centre (NSC), a BREEAM "Outstanding" building (built by Mace), using an advanced Life Cycle Assessment (LCA) methodology that integrates real-time key performance indicator (KPI) data from the construction phase. This novel approach addresses limitations in conventional LCA, such as reliance on generic datasets and low temporal resolution, by utilizing detailed data from Mace's Optimise platform, which tracks material use, energy consumption, and waste generation.

The LCA was conducted across the entire building lifecycle—from raw material extraction to end-of-life—following EN 15978 standards. Results revealed that construction activities, particularly material production and installation, dominate environmental impacts, contributing 80-90% of embodied carbon and significant shares of resource depletion and toxicity impacts. The integration of KPI data enabled detailed phase-by-phase impact assessments, identifying hotspots in the substructure and mechanical, electrical, and plumbing (MEP) phases. Retrofit and end-of-life scenarios were also evaluated, showcasing potential reductions of up to 90% in environmental impacts when adaptive reuse strategies are employed over conventional demolition.

This study underscores the critical importance of integrating project-specific data in LCA to enhance accuracy and decision-making in sustainable building design. The findings provide actionable insights for reducing embodied carbon, optimizing material selection, and advancing sustainability practices in higher education infrastructure. The methodology sets a benchmark for future LCA studies, offering a scalable framework for more robust environmental impact evaluations in the construction industry.

Assessing GHG Emissions in the EPC Contractor field: Challenges and Contributions

Noriko Tatsumi

JGC Global, Japan

Celebrating its 96th anniversary, JGC Group, an EPC contractor, has executed 20,000 projects in 80 countries worldwide. Since 2021, JGC has started calculating GHG emissions from its corporate activities. However, unlike the more common product-based emission calculations, calculating Scope 1, 2, and 3 emissions for the plants and factories that manufacture these products and raw materials is challenging due to insufficient data. Leveraging its extensive EPC project execution experience, JGC proposes setting assumptions that enable more accurate calculations. While various calculation methods for LCA in construction and building have been defined in these days, the unique challenges of the EPC contractor indu-

stry have yet to be shared. By sharing the assumptions and challenges in our calculation process, we are confident that we can contribute not only to the standardization of calculations among similar businesses but also to improving the accuracy of GHG emissions in the product industry.

In response to growing concerns about climate change, there is an increasing societal demand for the calculation and disclosure of GHG emissions from corporate activities. While many businesses conduct LCA of products manufactured by their "plants", there are very few examples of evaluating the plants themselves. This is due to the uniqueness of each plant facility, the complexity of dividing the scope of work in diverse procurement and construction processes, the inability to fully grasp the actual operating conditions after the plant is handed over, and the irony that the plant itself emits GHGs, making it difficult to fully understand its environmental impact. Based on the huge past experiences, JGC sets assumptions applicable to almost all facilities. Additionally, since GHG emissions during the plant's operation period become the direct emissions of the end-user, we contribute to reducing emissions across the entire supply chain by proposing optimal process designs to customers.

Distribution of life cycle impacts for housing in Denmark

Marion George, Olivier Jolliet

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Residential buildings account for a third of the carbon emissions of Denmark, bringing an urge to mitigate their impact. This project focuses on the life cycle impacts of the Danish housing realm and its main determinants.

Energy labels were collected for 863 631 Danish dwellings, complemented with environmental and occupancy data and used within an overall equation to determine the environmental impact per capita of any Danish dwelling based on its energy label, building living area, heating and building types and living area per capita.

From the heating consumption ranging from 14 kWh/m2 to 330 kWh/m2, determined through regressions based on the energy label and the building living area, both the heating and the building types influence the environmental impact per square meter. The living area per capita, varying between 19 and 110 m2/cap (2.5th and 97.5th percentiles), with an average value of 52 m2/cap, leads to individual impacts, yielding an average carbon footprint per capita of 2.2 tCO2e/cap/yr (95% percentile interval: 0.48 to 5.9 tCO2e/cap/yr). A variability analysis highlights the living area per capita as a main determinant across impact categories, with an average contribution of 53%. The energy label and the heating impact intensity appear to have highly varying influences over different categories, while the embodied impact remains below 10%.

Finally, we used an absolute environmental sustainability approach, considering a boundary of 110 kgCO2e/cap/yr to limit global temperature increase to 2°C. Absolute sustainability would only be achieved with e.g. a 22m2-apartment for 2 occupants, energy labelled A2020 with district heating, which seems hardly achievable in the current society.

As a conclusion, bringing the existing building stock to the energy label A would substantially improve the environmental impact of housing in Denmark, but is not sufficient to reach the boundary corresponding to a 2°C-increase for climate change.

A Comprehensive Guidance Tool for Sustainable and Circular Construction Waste Management

Teresa Ros Dosdá[1], Silvia Solsona Catalán[1], Lucía Nogales[2], Jan Valentin[3], Georgia Nikolakopoulou[4], Theodoros Theodosiou[5], Theodoros Theodoridis[6]

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The construction industry accounts for 35.7% of waste generated in the EU, primarily during construction and demolition phases. The RECONMATIC project (Horizon Europe prog. No. 101058580) tackles this pressing challenge by developing tools, advanced technologies, and digital, automated, and robotic systems to prevent and manage Construction and Demolition Waste (CDW) across all stages of the building and infrastructures life cycle. Backed by an international consortium and six demonstrators, the project aspires to achieve a zero-waste construction industry, setting a benchmark for sustainability in the sector.

This paper presents a systematic guidance tool designed to integrate sustainability and circularity into technological innovations for CDW management throughout the entire building and construction life cycle.

The tool, developed in collaboration with key stakeholders, is a practical and adaptable resource tailored to non-experts across the value chain, including designers, architects, civil engineers, construction and demolition professionals, material manufacturers, asset managers, waste managers.

The methodology underpinning the tool enables users to prioritise, implement, and evaluate sustainability and circularity solutions based on their importance, urgency, and feasibility. The tool incorporates comprehensive metrics aligned with major sustainability assessment schemes, international standards, guidelines, regulations, and complementary research initiatives. Its framework evaluates 110 indicators categorised into five dimensions: environmental, social, economic, technical, and management and governance.

The tool delivers actionable recommendations to enhance and effectively communicate sustainability and circularity performance. Validation will take place through six demonstrators that will apply technologies in building and infrastructure projects at various stages of their life cycle, as well as in recycling plants.

RECONMATIC guidance tool marks a substantial advancement in integrating sustainability and circularity into CDW prevention, minimisation, and valorisation. Its holistic and adaptable design positions it as an essential inspirational resource to drive the transition towards sustainable construction practices, aligning seamlessly with the goals of the SDGs and Life Cycle Management.

Towards Sustainability in the EU Construction Industry: Addressing Barriers in Concrete Waste Recycling

Mafalda Silva, Mehrdad Ghorbani Mooselu, Anne Rønning

NORSUS, Norway

The construction and demolition waste (CDW) sector, particularly concrete waste management, plays a critical role in the transition towards a more circular economy and increased sustainability in the construction industry. However, despite EU efforts to promote sustainable CDW management, challenges remain in implementing life cycle sustainability assessment (LCSA) and circular practices.

This study focuses on concrete waste management practices from the CDW sector in selected European countries and aims to identify the barriers that hinder the recycling of concrete waste as well as the use of recycled concrete aggregates (RCA) in higher-value products. Therefore, this study aims to contribute to the ongoing discussion on the implementation of measures towards a more sustainable construction industry that is in line with the ambitious European sustainability targets.

Study findings highlight the importance of the national degree of freedom to increase the use of RCA to address local variations in material availability, industry practices, and environmental priorities. It also calls

for defining new applications for recycled materials, particularly RCA, to expand their market potential and reduce their reliance on virgin resources.

Furthermore, the findings highlight the importance of collaboration among key stakeholders to address the gaps between current practices and the EU's sustainability targets. Life Cycle Assessment (LCA) is identified as a vital tool for quantifying environmental, social, and economic impacts in CDW management. Aligning concrete waste recycling with LCSA principles is essential for achieving sustainable concrete waste management and positioning the EU as a leader in circular construction and demolition waste practices.

Benchmarking Emissions during Construction: A Prospective LCSA Approach

Lea Hasselsteen, Harpa Birgisdottir, Kai Kanafani

Aalborg University, Denmark

The construction industry is pivotal in global greenhouse gas emissions, contributing significantly to environmental impacts. In response, many countries are implementing regulatory measures requiring life cycle assessments and setting stringent CO2e emission thresholds. Denmark, for instance, mandates a limit of 1.5 kg CO2e/m^2 year for the construction processes, modules A4 and A5, with initial compliance expectations set at approximately 50% of current practices for new buildings. This study focuses on the prospective Life Cycle Sustainability Assessment (LCSA) of construction activities, particularly estimating the environmental impacts associated with waste generation during construction. By utilising scenario-based data for the end-of-life stages from Environmental Product Declarations (EPDs) of various product categories, this research provides practical emission factors for different waste fractions. These factors can be used to estimate the environmental impact of waste generation. The study aims to establish implementable benchmark values for emissions before construction begins, thereby enhancing the reliability of LCSA as a tool for reducing environmental impacts. Data from 307 previously constructed buildings are analysed to estimate waste handling and treatment emissions. The assessment uses waste percentages derived from case studies and literature. By examining the current compositions of building materials, this research offers insights into the emissions associated with construction waste management. These findings are crucial for understanding the potential for emission reduction strategies in future construction processes. Ultimately, this study contributes to the advancement of LCSA in the building sector by providing a more comprehensive and circular view of buildings' life cycle stages. It underscores the importance of accurate data and tailored scenarios in enhancing the sustainability of construction practices, aligning with global efforts to mitigate climate change impacts.

Integrating Circular Economy and LCSA in Urban Nature-Based Solutions

Mehrdad Ghorbani Mooselu[1], Anne Rønning[1], Ole Jørgen Hanssen[1,2], Mafalda Silva[1]

[1]NORSUS, Norway; [2]Norwegian University of Life Sciences

The integration of the Life Cycle Sustainability Assessment (LCSA) in the building and construction industry presents unique opportunities for improving the sustainability of urban runoff management systems. Such systems often suffer from high costs of construction and maintenance, resource scarcity, and lack of climate adaptation. As a complementary solution, nature-based solutions (NBS) combine quantitative and qualitative stormwater control with ecological benefits while generating social and economic advantages. Despite their potential, the sustainable development of NBS in urban settings with high population density and complex built environments faces significant challenges, including maintenance complexity, engaging the local community, and measuring biodiversity and social benefits.

This study identifies critical gaps in the sustainability of NBS, such as the need for integrating circular eco-

nomy principles and establishing standardized metrics for comprehensive assessments, including Environmental and Social Life Cycle Assessments (E-LCA and S-LCA) across their life cycle stages. The findings reveal that critical aspects such as carbon sequestration potential, biodiversity metrics, social conflicts, and stakeholder buy-in are often overlooked in the sustainability assessment of NBS.

This study emphasizes the need for cross-disciplinary collaboration and pilot projects in urban areas to address existing gaps in the LCSA of NBS and advance sustainable urban development. Proposed outcomes include replicable frameworks for diverse urban settings, capacity-building for decision-makers, and circular innovations in developing NBS.

Integrating Indigenous and innovative Building Culture into a Prospective Life Cycle Assessment Methodology

Nathalie Glenn[1], Alexander Passer[1], Kai-Kristina Lattrich[2]

[1]TU Graz, Austria; [2]Hochschule Ruhr West, Germany

Introduction: In the construction industry, the importance of a Life Cycle Assessment (LCA) is clear, given that 40% of CO^2 emissions in Germany can be attributed to buildings as well as 54% of waste generation. In this context, the function of an LCA is to provide quantitative decision support to enhance control and mitigate these adverse effects. The attributional LCA is based on current or past database representations of processes and is designed to evaluate products or services at a micro level. In contrast, the consequential LCA focuses on future effects, quantifying the effects of changes to processes or materials. Consequential LCAs use a specialised background database in the inventory. The emerging field of prospective LCA considers advancements in technology, energy and fuel supplies, CO^2 capture and climate change when assessing impact. It supports long-term and large-scale decision-making.

Research gap: The complexity of buildings, due to the variety of materials used and the incorporation of less commercialised indigenous products or new, innovative materials, poses challenges in LCA. This work aims to contribute to future-oriented LCA, focusing on modern indigenous design and innovative methods in LCA for buildings, components and materials.

Methods: A systematic literature review will be conducted to determine the current state of research in context-specific assessment methods for the environmental impacts of buildings, environmental impact criteria, and appropriate methodologies. Before conducting case studies, the potential and limitations of each LCA type must be determined. The case studies will be the primary focus of the research.

Evaluation: The results will be summarised and documented to evaluate their significance and applicability. A critical review will consider whether the methods are technically and scientifically appropriate, and whether they use sufficient data in relation to the objective of the study.

Analysis of Database Knowledge Gaps in LCA Tools: A Comparative Study of tallyLCA and OneClickLCA in Life-Cycle Stages C and D

Mathew Song[1], Ashley Juraschka[1], Joyce Kim[1], Carl Haas[1], Aryan Hojjati[2], Jun Ahn[2], Mehdi Ghobadi[2]

[1]University of Waterloo; [2]National Research Council Canada

Life Cycle Assessment (LCA) tools are essential for achieving credits in green building certifications and for embodied carbon reporting needed for regulatory compliance. However, the accuracy and relevance of LCA results are often affected by tool-specific assumptions, data gaps, and regional variability. This is especially true for Stages C&D (end-of-life and benefits beyond the system boundary), where the variability in waste management and material recovery introduces major uncertainties. While Stage A (product stage) has traditionally been the primary focus, the importance of Stages C&D is increasing as efforts grow to support

reuse, recycling, and multi-life-cycle considerations.

This study examines the impact of data gaps, assumptions, and regional differences for end-of-life pathways on global warming potential (GWP) results in Stages C&D, with a focus on North America. The analysis begins with a hotspot study to evaluate the significance of Stages C&D within a whole-building LCA, providing context for their relative contribution to overall impacts. The paper then investigates how LCA tools tallyLCA and OneClickLCA handle assumptions about reuse, recycling, and energy use for building materials.

To determine which assumptions and defaults have the greatest impact on GWP, a comparative case study is conducted on floor assemblies made of cross-laminated-timber, cast-in-place and hollow-core concrete. The study evaluates the influence of key factors, including reuse rates and cycles, waste stream pathways, material quality, and regional transport distances. Preliminary results indicate that these assumptions can alter GWP by over 50%, underscoring the need for more consistent assumptions and better alignment across LCA tools.

These findings provide guidance for LCA practitioners, tool users, and policymakers on navigating tool variability and prioritizing assumptions. The study also identifies opportunities to harmonize tool defaults and enhance data quality, supporting region-specific LCA inputs for North American green building certifications and circular economy efforts.

LP3: Lunch & Poster

Time: Friday, 12/Sept/2025: 1:00pm - 2:30pm

Overcoming Barriers to the Implementation of LCA in the Plastics Industry

Merlin Pohler, Hans-Josef Endres

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Life cycle assessment (LCA) has become an important tool for evaluating and communicating the environmental impact of products and for supporting sustainable decision-making in the industry. However, the implementation of LCA in companies is associated with considerable challenges, especially when it comes to harmonizing established legal and scientific standards, norms and frameworks with the processes and structures of everyday industrial life. The presented research develops a structured approach to overcome these challenges from the perspective of a company in the plastics sector in order to systematically integrate LCA practices into its operations.

The approach consists of two core components. The first outlines the organizational requirements for the effective implementation of LCA in a company, such as the development of necessary awareness and knowledge for carrying out LCA or the creation of workflows within the company to ensure efficient management of primary data. This foundation serves to enable a consistent, reliable and efficient application of LCA methods. The second component focuses on industry-specific recommendations tailored to the plastics processing industry. These include the allocation of recycling processes, the management of bio-based raw materials, and the harmonized handling of process data at different production locations worldwide. The subjects were defined in cooperation with a company from the plastics manufacturing industry and are evaluated and answered taking into account existing EU directives, scientific frameworks and industry sector-specific guidelines.

The results of this research provide actionable strategies to overcome methodological and practical barriers to LCA implementation. These strategies help organizations use LCA effectively for regulatory compliance, ecological improvements, strategic decision-making, and communication. Focusing on the challenges and opportunities in the plastics manufacturing sector, this research supports companies in implementing product sustainability assessment while providing transferable findings for broader adoption of LCA practices across other manufacturing sectors.

Assessing the environmental impacts of a domestic water heater panel

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Plastic polymers are widely used as engineering plastics due to their physicochemical properties and ease of moulding. Although the plastic sector contributed only 4% of global carbon dioxide equivalent (CO2 eq) emissions in 2023, its share is projected to rise significantly, reaching 15% of total CO2 eq by 2050.

This study presents a Life Cycle Assessment (LCA) to evaluate the environmental performance of a domestic water heater panel —produced from a polycarbonate/acrylonitrile butadiene styrene (PC/ABS) blend— from a cradle-to-gate perspective. The functional unit is defined as a single panel for a domestic water heater weighing 1.25 kg.

The results show that the production of the PC/ABS blend is the hotspot in all impact categories studied (global warming, terrestrial acidification, freshwater eutrophication, marine eutrophication, mineral resource scarcity, and fossil resource scarcity), ranging from 53% (mineral resource scarcity) to 86% (freshwater eutrophication). Within the blend, PC contributes more to environmental impacts, mainly due to the use of

bisphenol A in its production.

Electricity consumption during panel production is the second hotspot in four of the six environmental impact categories, ranging from 8% (fossil resource scarcity) to 18% (terrestrial acidification). A sensitivity analysis was conducted to explore the potential environmental benefits of increasing the electricity production from the photovoltaic panels installed in the panel company by 11%, reducing the same amount of electricity consumption from the national grid. This analysis revealed a limited reduction of up to 3% across all impact categories under study. These findings highlight the need for further research to develop functional alternative raw materials that can replace fossil-based polymers, enabling the production of engineering plastics with improved environmental performance.

Comparative Life Cycle Assessment of In-wall Flushing Cisterns

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The construction sector involves high consumption of materials, energy, water, and emissions into the environment. Therefore, there is a need to evaluate their environmental impacts, in order to adopt more sustainable practices. In this context, Life Cycle Assessment (LCA) is a reliable tool capable of identifying, quantifying, and comparing the environmental impacts of products. This study applies LCA to compare the environmental impacts associated with the life cycle of five different types of in-wall flushing cisterns from a "cradle to grave" perspective. The products have the same water storage capacity but differ in the amounts and type of materials that compose them, as they were developed to be installed in different types of walls (solid brick-lined, solid or drywall) and toilets (floor-mounted or wall-hung). Real and specific data were collected from the production unit for the manufacturing processes of the in-wall flushing cisterns. For background data, generic data was used, preferably from the Ecoinvent database. The impact assessment method used was the "Product Environmental Footprint", including impact categories such as climate change, acidification, freshwater eutrophication, depletion of abiotic resources – minerals and metals, and depletion of abiotic resources – fossil fuels. The results demonstrate that most of the environmental impacts are from raw material production (mainly plastics and steel). The results also show that the impacts vary widely depending on the flushing cistern type. For example, the total climate change impact is about five times higher in the free-standing flushing cistern than in the lighter flushing cistern, mainly due to the steel frame present. In conclusion, this study shows the variability of the environmental impacts of the products evaluated, thus supporting consumers in their choices. Besides, it also supports the industry in the definition of strategies to decrease the environmental impacts of the main hotspots.

Pre-Emptive Life Cycle Management of Agriculture, Forestry and Bioindustry for Regional Resources Valorization

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Carbon neutrality is an urgent global challenge. At the same time, it is also necessary to consider how to design and build a "Beyond Carbon Zero Society" in which local industries and residents can receive benefits from decarbonization. To solve these problems, biomanufacturing must be addressed through a symbiotic relationship between agriculture and forestry, which converts atmospheric CO2 into carbohydrates, and industry, which produces high-value-added bioproducts while reducing greenhouse gas emissions.

For example, on Tanegashima, a remote island in Japan, an industrial symbiosis between agriculture and forestry (i.e., sugarcane and wood production) and bioindustry (i.e., raw sugar and alcohol production through crystallization and fermentation, and biochar and bio-oil production through torrefaction of lignocellulo-

se) is being implemented to realize the "Beyond Carbon Zero Society."

In this study, we tackle total system design and plant-scale demonstration of multiple industrial applications from multiple biomass feedstocks through life cycle assessment (LCA). Plant-scale demonstrations of ethanol fermentation from sugarcane-derived saccharides (sucrose, glucose, fructose) and torrefaction from bagasse and wood chips were conducted on Tanegashima. Through cross-breeding, high-yielding sugarcane was designed and developed as a suitable feedstock for multiple bioproducts such as raw sugar, ethanol, biochar, and biogas oil. The torrefaction process was designed to maintain year-round operations by changing the feedstock from bagasse to wood chips during the non-harvesting season of sugarcane.

The LCA results revealed that symbiosis of agriculture, forestry, and industry could reduce GHG emissions in both agriculture and industry, increase food and energy production simultaneously, and activate the local economy. Future discussions should include quantifying the environmental contribution of bioproducts based on LCA, developing a certification system to obtain economic benefits, and fair distribution of benefits in the supply chain.

Life Cycle Assessment and Biodiversity Footprint of the Global Spice Production

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Agriculture accounts for approximately one-third of global greenhouse gas (GHG) emissions and is the leading cause of biodiversity loss, highlighting the need to assess the environmental impact of all crops. The spice sector has been largely overlooked, with limited life cycle assessments of spices available. This study analysed the environmental impacts of 12 spices (capsicum, cardamom, cinnamon, cloves, cumin, ginger, nutmeg, mace, pepper, saffron, turmeric, and vanilla) in terms of climate change, acidification, land use, water use, and biodiversity impact, and evaluated the spice sector's role within the agriculture sector. The Environmental Footprint 3.1 method was employed for midpoint and single-score assessments. Additionally, three biodiversity assessment methods, ReCiPe, LC-Impact, and the high-resolution land-use intensities and fragmentation method (LUIF), were applied and compared. A combination of LC-Impact and LUIF proved to be the best biodiversity assessment method by integrating multiple impact categories and adopting LUIF's updated, regionalised land-use approach. The spice sector emits 52.1 Mt CO_2-eq annually, with the most significant contributors being capsicum, cumin, pepper, and ginger. Conventional saffron, vanilla, and cardamom have the highest global warming potential per kilogram. Critical hotspots include mineral fertiliser use and land-use change emissions, as well as retail glass packaging. The sector threatens 5,740 species with extinction annually, driven by ginger, capsicum, pepper, and turmeric, while saffron and vanilla show the highest species loss per kilogram. Major biodiversity hotspots are land occupation and mineral fertiliser use. Although the spice sector represents only 0.18% of agri-food turnover and 0.06% of the agri-food sector's production volume, it disproportionately contributes 0.325% of the agriculture sector's GHG emissions. Minimising fertiliser use and opting for plastic packaging instead of glass are the most promising strategies to reduce GHG emissions. Additionally, reducing mineral fertiliser input and increasing yield could drastically decrease species loss.

Impacts of brazilian wheat production on human health, ecosystem quality and resource scarcity

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Agriculture is the challenge of increasing production while promoting environmental sustainability by reducing impacts on human health, ecosystem quality and natural resources. Wheat, as one of the major commodities of the world, plays a critical role in global food security. The wheat production reached 785 million metric tons across 242.7 ha harvested, in 2023/2024. Life cycle assessment (LCA) is a robust tool for evaluating the environmental impacts of a product or service. The aim of this study was to assess the endpoint categories, human health, ecosystem quality and resource scarcity to support the scientific debate on the sustainability of Brazilian wheat cultivation. For this purpose, 61 wheat farmers in Southern Brazil, the country's main producing region, were surveyed. The farms were categorised into two groups: 17 large (ranging from 145 to 697 ha) and 44 small (ranging from 7 to 123 ha) with average productivity of 4.039 and 3.559 kg ha-1, respectively. The functional unit was defined as one kilogram of cultivated wheat. Environmental impacts were analysed using the ReCiPe 2016 Endpoint (H) 1.09 method and the SimaPro 9.6.0.1 software. The results showed impacts of 1.07E-6 and 1.41E-6 DALY for human health, 1.27E-8 and 1.55E-8 species yr for ecosystem quality, and 2.22E-02 and 2.61E-02 USD2013 for resource scarcity, for large and small farms, respectively. Small farms exhibited higher impacts than large farms, primarily due to their lower yields, secondly due to low efficiency of inputs and excessive field operations. These findings establish parameters for developing strategies to reduce the environmental impacts of Brazilian wheat cultivation, promoting more sustainable agriculture practices.

Hay production in Sicily: Life Cycle Assessment of a case study across two seasonal yields

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Hay production is essential for livestock farming with Italian forage crops covered approximately 6 million hectares in 2023. However, forage production is highly sensitive to climatic variation, which can significantly affect yields, increasing the environmental pressure per unit of product.

This study employs Life Cycle Assessment (LCA) to assess the environmental impacts of mixed hay production from different mediterranean forage species. Data were collected from a farm located in Cammarata (AG), Sicily, over two growing seasons: a high-yield (HY) season in 2021-2022 and a low-yield (LY) season in 2023-2024.

A "cradle-to-gate" system boundary was defined, covering the production and transport of inputs and field operations up to hay bale transport to the barn. Two distinct functional units (FUs) were employed: yield-scaled (ton of hay) and area-scaled (hectares of cultivated land).

The LCA, performed using SimaPro 9.5.0.2 and the CML-IA baseline V3.09 / EU25 method, revealed that the choise of FU had a significant influence on the interpretation of environmental performance. In the LY season, impacts per tonne of hay were approximately 70% higher than in the HY season due to lower yields. However, when assessed per hectare, the difference was around 20%, with slightly higher impacts in the HY season, suggesting that agronomic practices remained consistent, and environmental pressure per unit area did not change significantly.

Marine Aquatic Ecotoxicity per yield-scaled FU increased from 2.66E+05 (HY) to 1.02E+06 (LY) kg 1,4-DB eq. Similarly, GWP100a increased by a factor of 3.3, rising from 155 kg CO_2 eq in the HY season to 512 kg

CO_2 eq in the LY season, reflecting higher input requirements and increased emissions per unit of biomass.

Normalization of results showed the previous categories as the most affected, representing the primary areas of concern. Adaptive strategies will be essential for ensuring sustainable hay production while maintaining productivity.

Life cycle assessment of black soldier fly frass: balancing the benefits and trade-offs

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As the global population continuously grows, intensive agriculture practices to increase crop productivity often result in the extensive use of mineral fertilisers, leading to environmental degradation. Bio-based alternatives, such as organic fertilisers, have emerged to reduce reliance on mineral fertilisers while maintaining food security. Among novel organic options, insect frass, a co-product of insect production, has entered the market as a new nutrient source for crop production. It contains valuable nutrients, such as nitrogen, phosphorus, and organic matter, which support plant growth and improve soil health. From a life cycle perspective, organic fertilisers may offer the potential to reduce greenhouse gas emissions compared to mineral fertilisers. However, the environmental benefits of organic fertilisers depend on specific characteristics of the fertiliser, application strategies, and local conditions, which can lead to increased impacts in other environmental categories, such as eutrophication and ecotoxicity.

This study conducted a life cycle assessment (LCA) to evaluate the environmental impacts of black soldier fly (BSF) frass from production until application to soil. The leaching of heavy metals and nutrients present in frass, along with their corresponding impacts, which are often overlooked in previous studies, were included in this study. A comparison with the environmental impacts of mineral fertilisers was also performed. The ReCiPe 2016 method was chosen for the impact assessment, covering categories such as global warming, ecotoxicity and eutrophication. Sensitivity analyses were conducted to explore the variation of frass-specific characteristics, which depend on the insect feedstock.

The results indicate that BSF frass has the potential to serve as an alternative fertiliser, particularly in terms of reducing the global warming impact. Further research is needed to refine key assumptions that influence the outcomes in impact categories such as ecotoxicity and eutrophication.

Social sustainability assessment of insect-derived products: a procedure for social indicators selection

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The growing need for feed and food products has driven the agri-food sector to explore innovative and sustainable solutions, with insect-derived products standing out as nutrient-rich alternatives promoting a circular economy. Evaluating the social sustainability of these products through social life cycle assessment (S-LCA) is crucial but presents several challenges. Notably, defining relevant social indicators is critical to ensure the robustness of S-LCA. However, the high number of existing indicators represents practical challenges, as data collection can be limited and time-consuming. To address this challenge, the present study aims to develop a materiality assessment procedure, which involves selecting social indicators based on data quality and stakeholder preferences.

The first step of the procedure involved the pre-selection of subcategories amongst those recommended

in the UNEP methodological sheets for subcategories in S-LCA based on their importance to the insect production industry and compatibility with the Product Social Impact Life Cycle Assessment (PSILCA) database used to conduct the S-LCA. The second step focused on the pre-selection of indicators within each subcategory considering data quality criteria (geographical coverage, temporal coverage and completeness coverage) of available datasets in PSILCA. This process resulted in the pre-selection of 31 indicators (13 subcategories). In the third step, surveys directed to relevant stakeholders across the product's value chain – workers, value chain actors, society, local community, and consumers – were developed to define the final list of indicators. These surveys predominantly use multiple-choice questions on a Likert scale (1 = not important to 5= very important), supplemented by open questions (e.g. 'Indicate other social issues that you consider important to be addressed when evaluating this sector') to capture emerging industry-specific concerns. Although this study focuses on the insect production sector as a case study, the proposed procedure can be applied to other industries and sectors.

Economic sustainability assessment of insect-derived products: a contribution for a holistic sustainability approach

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The increasing importance of sustainable agriculture and innovative food value chains has driven interest in exploring new products and processes, including insect-based foods. This study aims to contribute to the economic sustainability assessment of infood, infeed, infrass products, particularly focused on the insect food sector in Portugal. It combines three models: input-output matrix analysis; Economic Surplus Model (ESM), and; Techno-Economic Analysis (TEA), it the goal of identifying critical bottlenecks and opportunities across the insect-based food supply chain, addressing both upstream and downstream impacts to optimize the value chain processes.

The input-output matrix analysis allows us to understand how the insect-based food sector interacts with other sectors in the economy (e.g. agriculture, animal production, etc), emphasizing their interdependencies and secondary effects. Additionally, the ESM assesses the social benefits (e.g. alleviate poverty, job creation) derived from the insect-based food supply chain by measuring consumers' and producers' willingness to pay, alongside the broader socioeconomic benefits anticipated from the insect sector. The Techno-Economic Analysis (TEA) estimates the costs associated with implementing the supply chain (e.g. economic competitiveness through capex and opex) to evaluate the project's financial sustainability.

The study uses primary data from companies participating in the value chain of the insect-based food industry sector, incentivized by the Portuguese Resilience and Recovery Plan Project INSECTERA. this innovative approach offers a more comprehensive understanding of the economic challenges and opportunities associated with insect-based foods, that can be further combined with the Life Cycle Assessment to quantify the resource efficiency and overall sustainability of the chain.

Towards a sustainable valorization of seafood side-streams: a critical review of environmental, economic and social assessment approaches

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The global production of seafood reached 174.9 million tons in 2021, with seafood processing generating substantial by-products (30-70%), such as heads, bones, guts, and shells. These by-products, rich in valuable compounds like proteins, oils, vitamins, minerals, pigments, and enzymes, present opportunity for valorization, contributing to the circular economy and resource efficiency. However, ensuring the sustainability of valorization technologies for seafood side-streams requires a holistic assessment of environmen-

tal, economic, and social impacts.

This systematic literature review examines sustainability assessments of seafood side-stream valorization technologies, analyzing trends, gaps, and methodological advances across the three sustainability pillars. It also evaluates the species, side-stream type, industry of application, and Technology Readiness Level (TRL).

This study reviewed 37 peer-reviewed articles: 21 conducted environmental assessments, 8 economic assessments, 7 examined both, and only one addressed all three sustainability pillars. Most research focused on valorizing seafood viscera from fish, primarily for feed industry applications, through enzymatic hydrolysis and solvent extraction, which exhibits high TRL. Life Cycle Assessment (LCA) was the dominant method for evaluating environmental impacts (26 papers), with 96% of papers assessing impacts on Global Warming, 73% on Terrestrial Acidification, 58% on Freshwater Eutrophication and Utilization of Fossil Resources. The standardized method for economic assessment were Techno-Economic Assessment (TEA) and Life Cycle Costing (LCC); other studies used metrics like OpEx, CapEx, and Net Present Value. Only one study integrated all three sustainability pillars through a multicriteria optimization framework using satisfaction of social needs to represent the social pillar.

Despite advances in environmental and economic evaluations, social impact assessment remains underexplored. The lack of standardized methods across all pillars highlights the need for harmonized assessment frameworks. Expanding research to other seafood species and higher-value applications presents further opportunities. This review underscores the importance of multidisciplinary approaches, offering a clear roadmap for future research in seafood valorization .

Prospective Life Cycle Assessment of Cellulose Nanofiber-Reinforced Plastics Produced by the Reactive Processing Method, Considering Continuous Production and Scale-up for Industrialization

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Cellulose nanofiber-reinforced plastics (CNFRPs), composites of nanofibrillated plant-derived pulp, have become possible substitutes for conventional structural materials because of their advantageous properties of lightness, stiffness, and recyclability. The reactive processing method is one of the emerging technologies for producing CNFRPs, which promotes the nanofibrillation of cellulose during kneading and simultaneously disperses it into the base polymer, and therefore, is expected to reduce life cycle greenhouse gas (LC-GHG) emissions from the production process. However, at this stage, the composites are usually produced by small-scale or inefficient processes, which makes proper evaluation challenging.

We performed prospective LCA for producing CNF-reinforced bio-polyethylene (CNF/bioPE) and CNF-reinforced polypropylene (CNF/PP) in comparison with talc-reinforced polypropylene (talc/PP), commonly used in automotive parts. These composite materials have been verified to meet the automotive parts standards for modulus of elasticity. The estimates are based on actual measurement data from laboratory-scale equipment, considering the influence of technological development and scale-up by industrial implementation. Using this data, we explored the possibility of replacing conventional reinforced plastics with these CNFRPs.

We found that LC-GHG emissions from CNF/bioPE at the industrial stage are lower than those from talc/PP. Assuming that re-kneading does not compromise the strength of these composites, introducing a recycling process would further increase the advantage of substituting talc/PP with CNF/bioPE. Conversely, the emissions from CNF/PP are slightly higher than those from talc/PP. This discrepancy is mainly due to the significant reduction in cradle-to-gate GHG emissions when producing bioPE, a benefit that arises from CO2 fixation during crop growth. The key advantage of this method for producing CNFRPs would lie in their ability to strengthen biomaterials to a practical level with low GHG emissions. Other impact asses-

sment results based on LIME2 will also be discussed.

Integrating Life Cycle Assessment in the Ecodesign of Emerging Biocomposites

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Biocomposites, particularly those made from bio-based resins and fibres, offer a promising and sustainable alternative to fossil-based materials. By utilising renewable bio-based resources, these materials can reduce dependence on fossil fuels. However, it is essential to assess their sustainability during the early design stages to ensure they deliver lower environmental impacts than conventional fossil-based products.

Life Cycle Assessment (LCA) is a well-established method for evaluating the environmental impacts of products and materials. However, its implementation throughout the development process of materials remains limited due to challenges such as limited data availability and uncertainties linked to the low technology readiness levels (TRLs) of emerging products.

This study proposes a framework for integrating LCA throughout the value chain of emerging biocomposites. It promotes close collaboration between sustainability assessors and product designers to embed environmental considerations into design decisions from the outset. The framework supports iterative application from the laboratory scale onward, enabling early identification of environmental hotspots and informing targeted ecodesign strategies. The method combines conventional LCA with prospective LCA, enabling the projection of future impacts for upscaled biocomposite inventories to address maturity discrepancies between the emerging bio-composites and their mature fossil-based benchmarks.

The framework is currently being applied in the Horizon SSUCHY-Next project, that is developing the supply chains for industrial hemp fibre and bio-based resins towards high performance circular bio-based composites. The approach enables multidisciplinary teams, including LCA practitioners, designers, and material developer, to assess and improve the environmental performance of biocomposites from an early stage. By generating forward-looking environmental feedback, the framework supports R&D and ecodesign choices well before full-scale production, contributing to more sustainable innovation pathways.

Comparison of Attributional and Consequential life cycle assessment of chicken meat and egg production in Brazil.

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Alternative proteins are critical to meet the demands of an increasing world population, while potentially reducing environmental impacts associated with current food systems. To quantify the environmental impact of novel foods, attributional life cycle assessments (ALCA) are commonly applied by academics, investors, and companies to gain insights and offer emission benchmarks. While decisions are frequently influenced by comparisons with these results, ALCA could not be used as a decision-support tool as the studied process or product is artificially isolated due to allocation rules. And because alternative proteins rely on raw biomaterials that are often multifunctional (i.e., for food, fuel, or feed), significant changes in demand for these raw ingredients will have environmental consequences arising from marginal suppliers of substitu-

ting or substituted products.

As one of the potentially substituted meats by alternative proteins, chicken products such as meats and eggs are commonly analysed using an attributional approach. Here, as a first step for future consequential life cycle assessment (CLCA) of alternative proteins, CLCA of chicken meat and eggs was conducted, specifically in the context of Brazil as it is the largest poultry exporter. The analysis applied CLCA principles to life cycle inventories in existing agri-food databases and literature. CLCA of chicken eggs shows higher emissions than the ALCA model as it inherits high emissions from land use change originating in maize and soybean within the compound feed. In spite of this, CLCA of chicken meat shows lower emissions due to the avoided production of meat and bone for feed, as it is being substituted by chicken by-products. This highlights the need to select the right LCA modelling approach for decision support and provides ready results for subsequent analysis of novel foods.

Future-oriented consequential LCA for timber wall elements made from recovered wood - a study in Germany, Sweden, and Finland

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As the global shift towards bio-based economies intensifies, increasing reliance on wood materials for construction and other sectors raises concerns about resource scarcity, environmental burdens, and the long-term sustainability of wood supply chains. Wood cascading—the sequential material use of wood—offers a promising alternative for addressing these challenges by prolonging carbon storage and reducing reliance on primary wood. While previous studies have assessed wood cascading's environmental impacts, many rely on attributional Life Cycle Assessment (LCA), which overlooks potential market shifts related to the introduction of recovered wood as raw materials. To fully capture the future environmental impacts resulting from these market shifts, a prospective consequential LCA (p-CLCA) is required. This study will apply a p-CLCA to evaluate the environmental implications of introducing newly developed timber wall and floor elements largely made of recovered wood. The study will include prospective scenarios that account for future technological developments, market dynamics, and energy system transitions and compare them with current primary wood-based designs. The anticipated outcome will be to quantify the environmental impacts related to market shifts, such as changes in the demand for primary wood due to increased use of recovered wood and shifts in fossil fuel consumption as recovered wood is increasingly allocated for material use in construction rather than energy production. The p-CLCA results will provide stakeholders with critical insights into the long-term environmental viability of wood cascading strategies for construction applications. The results will inform policymakers, industry decision-makers, and researchers, guiding resource management, product development, and policy interventions to foster sustainable bio-based economies and resilient wood supply chains.

Temporal analysis of photovoltaic technologies and their impacts on the planetary boundaries

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The current Holocene epoch provides the essential conditions for life on Earth. However, human development is threatening this delicate balance through technological advances and a surplus of greenhouse gas (GHG) being emitted into the atmosphere. With the global average temperature exceeding the critical threshold of +1.5°C above pre-industrial levels in 2024 for the first time, the need to transition to sustainable technologies becomes more urgent, especially as the world aims to achieve net-zero emissions by 2050.

The energy sector, responsible for 38% of global GHG emissions, stands at the forefront of this transforma-

tion. While electrical energy supply is still heavily reliant on fossil fuels, various developments towards renewable energy are progressively altering the global energy landscape. This study focuses on the evolution of solar technology, which has become a promising renewable energy source due to significant cost reductions and efficiency improvements in the last decade. The research aims to analyze the environmental impacts and economic development of different generations of solar technologies, including first-generation silicon-based panels, second-generation thin-film, and cutting-edge third-generation solutions such as perovskites and tandem cells. Using prospective LCA, the study examines the energy production efficiency and environmental impacts, while addressing how technological advances affect these impacts over time, including future scenarios in order to show the results of today's efforts. An eco-efficiency assessment incorporates the development of economic indicators, highlighting the potential cost reductions and efficiency improvements.

By relating the results to the concept of planetary boundaries, the study assesses whether advances in solar technology are sufficient to transform the energy sector in time. Through this comprehensive approach, the research aims to contribute to the development of a resilient energy future that operates within the environmental limits of our planet, ensuring a balance between technological progress and environmental sustainability.

How Future-oriented Social and Environmental Life Cycle Assessment Can Help Manage the Impacts of Innovations? Learnings from photochromic textile case study

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Innovations designed to enhance user experience or product appeal often increase environmental impacts, as seen with single-use coffee capsules and fast-charging technologies. These innovations, while convenient, result in higher greenhouse gas emissions compared to traditional alternatives. This work demonstrates a novel approach to estimating the future environmental and social impacts of emerging technologies using prospective Life Cycle Assessment (pLCA) and scenario-based Social Life Cycle Assessment (sLCA).

Our approach assesses innovations that prioritize product appeal, where the added value is not accounted for in LCA. By communicating the additional associated impacts stemming from the added value, stakeholders can better align technological advancements with sustainability goals at corporate, national, or global levels. Integrating scenario-based sLCA with pLCA provides a more comprehensive understanding of the potential risks and opportunities linked to emerging technologies.

A case study on photochromic fabrics—textiles that change color in response to UV light—demonstrates the applicability of this approach. The analysis considered multiple scenarios, including variations in fabric lifespan, substitution rates of conventional clothing, material sourcing, and dye incorporation levels. This scenario-driven approach highlights how diverse technology implementation pathways and future evolution of sustainability challenges influence potential environmental and social impacts.

The findings show the importance of conducting environmental and social LCAs aimed at estimating and addressing the impacts posed by emerging technologies. By offering actionable insights, this approach supports stakeholders in making informed decisions that balance product innovation with sustainability objectives, promoting technologies better aligned with long-term environmental and social goals.

Framework for assessing the sustainability and circularity potentials of wastewater treatment plants

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At present, the process of certification is mainly driven by two objectives: to verify the compliance of the organization's activities with standards and policies, and to promote the company's green credentials, thus increasing its market share. However, the certification of end-of-life processes stages is not fully covered, which hinders the possibilities of sustainable and circular improvement. In this context, the present research aims to provide a roadmap to facilitate the assessment of the performance of water and wastewater treatment plants towards sustainability and circularity. A six-step framework has been proposed, to serve as a basis for a future certification scheme for this sector, including: gathering mandatory requirements from legislation, proposing a classification system for the framework, selecting sustainability and circularity indicators, linking indicators to requirements, and testing and validating the methodology with case studies (two wastewater treatment plants). In addition, a template in the form of a fact sheet was created for end-users to collect data at the process level for quantifying or qualifying those indicators. The results showed that most of the indicators are qualitative and about 61% of the quantitative requirements of the framework could be calculated with the usual plant documentation. Finally, some gaps were identified, including the lack of thresholds for the indicators, the lack of guidelines for data collection, and the need of improvement of the legislation regarding circularity metrics in this sector.

This research has been supported by the BIORECER (No 101060684) funded by the European Commission HORIZON-CL6-2021-ZEROPOLLUTION-01. A. Arias also thanks the Galician Government for financial support (Grant reference ED481B-2023-072). S. Estévez also thanks to the Spanish Ministry of Science, Innovation and Universities for financial support (Grant reference PRE2020-092074).

Structured Decision-Making in Sustainability: Formalizing Fuzzy Logic (FL) for Multi-Criteria Decision Analyses (MCDAs)

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Decision-making in sustainability requires integrating economic, environmental, and social objec-tives—a task complicated by ambiguity and uncertainties. Traditional methods often oversimplify or fail to account for the inherent complexities of balancing these dimensions. Fuzzy Logic (FL) offers a robust alternative for supporting Multi-Criteria Decision Analyses (MCDAs), accommodating subjectivity and imprecision while fostering adaptive and holistic decision-making processes. Challenges in MCDAs often stem from aggregation methods (e.g., minimum, maximum, weighted averages), the definition of membership functions (binary versus degrees of membership), and factor weighting. These components are frequently oversimplified or lack transparency, undermining their ability to reflect real-world interdependencies and trade-offs. FL provides a structured yet flexible framework to address these limitations by incorporating nuanced modelling approaches.

This study introduces a transparent FL-based inference system tailored to sustainability-focused MCDAs. It defines adaptable rules that align with the economic, environmental, and social pillars of sustainability. Membership functions, such as triangular, trapezoidal, or Gaussian, are utilized to represent each criterion's unique attributes. Aggregation methods, including Mamdani systems for linguistic outputs and Sugeno methods for numerical outcomes, are systematically evaluated to optimize the integration of diverse metrics. Transparency is a cornerstone of the framework, enabling stakeholders to refine rules, weights, and functions in response to new data or changing priorities. By ensuring adaptability, this approach supports robust decision-making even as sustainability challenges evolve. Moreover, hybrid models combining FL with machine learning are explored to enhance the system's adaptability and predictive power. This FL-driven

framework bridges methodological gaps in MCDAs, offering a structured, transparent, and adaptive solution for addressing sustainability challenges. It supports data-driven decisions while providing stakeholders with clear insights into the complexities of multi-dimensional sustainability considerations.

From pilot to market: A holistic approach to sustainability assessment in emerging technologies towards a circular bioeconomy

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The transition to a circular bioeconomy presents significant challenges for bio-based products in achieving market competitiveness with respect to fossil-based alternatives. Nonetheless, these products offer key advantages, such as reduced raw material costs and environmental impacts, particularly when second-generation biomass is valorised. In this context, the use of biomass from phytoremediation processes emerges as a promising strategy to lower both economic and environmental impacts associated with bio-based production.

To evaluate this potential, Life Cycle Assessment (LCA) and Techno-Economic Analysis (TEA) are applied in an integrated approach from the early stages of technology development. Cost-Benefit Analysis (CBA) is also used to identify and monetise the external socio-economic costs and benefits of bioremediation. This study proposes the combination of LCA, TEA and CBA within the environmental Life Cycle Costing (eLCC) framework, incorporating the monetary valuation of externalities into the financial analysis.

Drawing on data from real bioremediation cases, the study aims to quantify the environmental benefits of pollutant removal, including avoided health impacts, and explores the socio-economic value derived from biomass valorisation. By comparing the production costs of bio-based and fossil-based processes, the study will assess the extent to which economic feasibility is reached, as well as the adjustments required for market competitiveness.

Challenges remain in optimising plant design and scaling up cost-effective valorisation technologies. To address this, learning effects will be analysed to estimate cost reductions and efficiency gains in lignocellulosic biomass valorisation at industrial scale.

This work demonstrates how life cycle-based methodologies can be combined to evaluate the full value of nature-based solutions and their role in the circular bioeconomy.

Integrating LCA, CSRD, and Digitalization: A Literature Review

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The implementation of the Corporate Sustainability Reporting Directive (CSRD) is driving European organizations and companies to improve their sustainability reporting. This regulation requires more rigorous and transparent methods to assess and communicate environmental, social and governance impacts. Among these, Life Cycle Assessment (LCA) has become a crucial tool for quantifying environmental impacts and providing accurate data. In this context, digitalization presents significant opportunities to optimize the LCA methodology and sustainability reporting through data collection, processing and communication. Technologies such as Artificial Intelligence (AI), blockchain and Internet of Things (IoT) improve traceability, pro-

cess automation and information management, increasing accuracy and reliability.

This study reviews existing literature to explore interactions between LCA methodologies, sustainability reporting and digitalization. Searching in academic publications keywords such as "life cycle assessment or life cycle thinking" and "Corporate Sustainability Reporting Directive or Sustainability reporting" and "digitalization or digital technologies" or artificial intelligence or Blockchain or IoT; the research identified three bilateral connections: i) LCA and sustainability reporting; ii) LCA and digitalization; iii) digitalization and sustainability reporting. Studies that fully integrate these three dimensions appear limited.

This review investigates how digital technologies enhance the accuracy and efficiency of LCA studies by automating data collection and analysis. It also explores how integration with sustainability reporting can promote more complete and transparent disclosures of corporate performance. The challenges and opportunities of new technologies, such as blockchain and AI, in improving the traceability, verifiability and reporting of sustainability data are examined. Therefore, this study provides an overview of current literature, identifying strategies to support policymakers, companies and researchers in the sustainable and digital transition.

Demonstrating Bio-Attributed PVC for Industry Applications: Aligning with EU's SSbD Framework and Advancing Circular Economy Goals

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Extreme weather events have significant consequences, impacting people's lives and causing substantial economic losses. The ten most destructive climate events have resulted in estimated changes of $170 billion. Climate changes exacerbated these phenomena leading to long-term changes in atmospheric conditions and affecting ecosystems, weather patterns, and human societies. Addressing climate change is therefor essential to prevent more frequent and severe natural disaster, biodiversity loss, and growing social and economic inequalities.

The Safe and Sustainable by Design (SSbD) framework, developed by the European Commission, aims to guide innovation in chemicals and materials to support the green and sustainable transformation of industries. This approach focuses on replacing harmful substances and minimizing health and environmental impacts throughout the entire product life cycle. Certain raw materials have been identified as hazardous, with potential endocrine-disrupting or allergenic effects, and some are already classified as Substances of Very Concern (SVHC) under the REACH regulation.

The ANALYST Project, introduces three key innovations: ANALYST-BOX, a robust methodologies to assess health, environmental, social, and economic impacts across the plastic value chain; ANALYST-DIGI, a FAIR (Findable, Accessible, Interoperable, and Reusable) open-access database to enable informed, impact-driven decision-making; ANALYST-T-PACK, a demonstration and validation programme covering three use cases within the PVC value chain.

Within the scope of this project, TMG Automotive will develop a demonstration and validation program for ANALYST-BOX and DIGI, leading use case 2, which focuses on replacing conventional PVC with bio-circular PVC and substituting a hazardous plasticizer with a safer, low-impact alternative. This process involves defining the scope, objectives, and technical requirements, as well as planning and monitoring the demonstration activities. It also includes identifying data gaps and refining the tools based on lessons learned. The outcomes will be used to produce replication cases, support adoption in other industries, and contribute to boarder policy development.

Environmental assessment for hydrogen in steel production as emergent technology

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Steel is a pillar of our society. It has a wide scope of applications and it is an important material for our sustainable growth. It is also considered a major contributor of greenhouse gas emissions due to its carbon-intensive production methods. In alignment with the global goal of climate-neutrality the steel sector is considered one of the hardest to decarbonize; due to the current production methods already operating at efficiency limits. Consequently, new approaches to steel production are needed. One of the most promising routes is the use of hydrogen in steel production; both as fuel and as a reducing agent where the potential of CO2 abatement is the highest for this production method. Hydrogen-based steel production is an emergent technology. Emergent technologies need different assessments at early stages of development for better evaluation of their potential especially towards decarbonization. This study focuses on an environmental assessment through lifecycle analysis (LCA) for a hydrogen-based steel production method, allowing for a basis for quantitative and comparative assessment of the emergent technology and paving the ground for future sustainability assessments on hydrogen-based green steel production as an emergent technology.

Using Life Cycle Assessment to support the selection of the most efficient circular economy strategies in the steelmaking industry: learnings from the ALCHIMIA, GreenHeatEAF and PURESCRAP projects

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Life Cycle Assessment (LCA) is the most widely used methodology to quantify the environmental impact of the steelmaking industry, but more recently it has successfully been used to support the investigation of circular economy (CE) and decarbonization strategies in the steel sector.

In this contribution we aim to illustrate how LCA can be used to support the decision-making process within the context of three research projects funded within the Horizon Europe programme.

In the first project ALCHIMIA "Data and decentralized Artificial intelligence for a competitive and green European metallurgy industry" the aim is to improve the performances of the steelmaking process through the application of digital technologies based on Artificial Intelligence techniques. LCA is used to optimize the scrap mix and the energy consumption flows based on Electric Arc Furnace (EAF) steelmaking plants and the key CE strategy implemented refers to the production of secondary steel from scraps.

In the second project PURESCRAP "Purity improvement of Scrap Metal the aim is to increase the use of low-quality scrap grades (post-consumer scrap) by deploying and applying best available technologies to reduce impurities. LCA combined with Life Cycle Costing (LCC) is used to assess the environmental and economic performance of the process before and after the PURESCRAP implementation.

Finally, the GreenHeatEAF project "Gradual Integration of REnewable carbon and alternative non-carbon Energy sources and modular HEATling technologies in EAF for progressive CO2 decrease" aims at investigating alternative CE and decarbonization strategies in the EAF process. The strategies considered are the replacement of natural gas and other fossil energy sources with hydrogen or renewable carbon sources (e.g. biochar), as well as the use of technologies to implement maximum heat recovery from off-gas and slag. LCA and LCC methods are used to assess the potential improvement after the implementation of the solutions in steelworks.

Integrating planetary boundaries in sustainable industrial transition: a review and case study on bio-based byproduct utilization pathways

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In the pursuit of remaining within a safe operating space to guarantee Earth's system resilience, an industrial transition to more sustainable practices is urgently needed. Although life cycle assessment (LCA) approaches can effectively inform transition pathways, they still mainly focus on relative comparisons and may fall short in steering the transition against absolute science-based targets. To contribute to addressing this gap, we explored the potential of integrating the planetary boundaries (PBs) framework with LCA. We conducted a critical analysis of integration approaches and tested their feasibility and effectiveness in a case study of transition pathways. In relation to the downscaling of PB to specific sectorial targets, we identified two main categories: (i) activity-based economic downscaling, and (ii) emission-based downscaling. We tested these approaches for Absolute Environmental Sustainability Assessment (AESA) of transition pathways from fossil-linear to bio-based circular value chains. The specific case of lignin extraction from the pulp and paper industry for the production of three biomaterials (anodes for batteries, plasticizers, and adhesives) at country scale was analyzed. Findings suggest that results are sensitive to the choice of allocation principle, base year, temporal scope of the study and the definition of acceptable levels of risk. Possible methodological improvements identified are the definition of sector-based targets based on the precautionary principle, and a better consideration of criticality and circularity. While the downscaling approach should integrate uncertainty analysis, the design of transition trajectories and the development of carrying capacity allocation approaches that better align with industrial capabilities to reduce and better direct production to overall societal wellbeing needs fulfillment. Overall, the AESA analysis allowed shortlisting the most promising production pathways and defining a technology-based target for redesign, thus complementing the results provided by conventional LCAs.

Building a Participatory Life Cycle Assessment Database to Drive Climate Mitigation and Sustainability in Vulnerable Municipalities and Key Sectors in Mexico

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This project aims to establish a participatory and publicly accessible Life Cycle Assessment (LCA) database tailored to municipalities in Mexico facing high vulnerability and marginalization. Focusing on key sectors such as agriculture, construction, and waste management, the initiative seeks to enable data-driven decision-making and implement impactful climate mitigation strategies. By fostering resource efficiency, reducing greenhouse gas (GHG) emissions, and supporting compliance with international trade regulations, the project contributes to Mexico's Nationally Determined Contributions (NDCs) and global climate goals.

The project comprises four main outputs: (1) the development of a comprehensive LCA database, providing high-quality, standardized data for use by academia, policymakers, and the private sector; (2) the establishment of a competence center serving as a platform for ongoing training, technical support, and networking for LCA practitioners across Mexico; (3) the implementation of pilot projects in agriculture, construction, and waste management to identify mitigation opportunities and create scalable models; and (4) targeted capacity-building efforts and knowledge dissemination to equip local stakeholders, including marginalized groups, with life cycle thinking skills and tools.

The initiative leverages a collaborative approach that combines local knowledge with global best practices, ensuring methodological rigor and alignment with international standards. By integrating local data into actionable strategies, the project empowers vulnerable communities to adopt sustainable practices, builds resilience, and supports the scalability of outcomes to other sectors and regions. This effort positions

Mexico to make significant progress toward sustainable development and meaningful contributions to climate mitigation efforts.

Integrating the Safe and Sustainable by Design (SSbD) Framework in the Development of Recycled Iron-Based Alloys

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The IRIDISCENTE project aims to develop a digital methodology for the intelligent design, processing, and characterisation of new iron-based alloys derived from recycled scrap materials. These alloys are intended for advanced manufacturing processes that reduce dependency on critical raw materials and promote circularity within the European steel industry.

To ensure that the development of these new materials aligns with safety and sustainability principles from the earliest stages, the project adopts the Safe and Sustainable by Design (SSbD) framework. This framework provides a structured approach for identifying and minimising potential risks and environmental burdens throughout the material life cycle. Within this context, our work focuses on the integration of safety, together with Life Cycle Sustainability Assessment (LCSA), criticality and circularity indicators in the algorithm behind the AI tool to select the steel scrap streams that will be the basis for the new alloys.

From the sustainability perspective, based on the analysis of scrap composition and impact data, the strategy will focus on optimizing the use of metals with higher environmental impacts, most critical and those with more circularity possibilities, achieving for each composition the highest technical performance and longest life. This approach will help ensure that these metals are safely reused in new alloy formulations instead of being lost or discarded as waste. Furthermore, this methodology highlights the relevance of coupling LCSA with the SSbD framework applying machine learning and digital tools for an enhanced recourse efficiency, safety and performance in the context of metallurgical innovation.

Sustainability in Delivery Drones: Life Cycle Impacts and Opportunities for Improvements

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While global parcel shipping volume is continuously increasing, this does not only challenge logistical systems, but also goes along with serious ecological impacts. Novel delivery methods are therefore investigated, to deal with the rising number of parcels while causing minimal environmental impact. A promising solution is seen in unmanned aerial vehicles (UAVs), whose ecological effects have already been compared to those of ground delivery methods in several studies. Nonetheless, aspects such as limited battery capacity, or breakage of rotor blades, are often disregarded, but significantly impair the environmental performance of UAVs. For further development and ecological improvement of UAVs and UAV components, such knowledge about environmental contributions of the individual parts and life cycle stages are essential.

By conducting a cradle to grave Life Cycle Assessment, this study has the goal to identify components and life cycle stages of delivery drones with main environmental impact and with highest potential to reduce the overall ecological effects. Aspects such as battery and blade replacements are encompassed in the model assumptions, including a sensitivity analysis for different replacement frequencies and electricity mixes.

Furthermore, it will be investigated how the three LCA system modelling approaches cut-off, APOS, and

consequential, influence the LCA results. This provides insights into the variability of outcomes based on methodological choices, highlighting their implications for the development of novel mobility solutions.

The findings of this study show the main environmental hotspots throughout the life cycle of delivery drones and offer recommendations for improving their environmental effects. By addressing aspects such as material recycling, component longevity and energy source optimization, this research aims to support the design and implementation of environmentally conscious UAVs. Ultimately, it provides a scientific basis for the development of sustainable mobility in the growing field of parcel logistics.

Influence of the simultaneous use of fiber-reinforced plastics and regenerative synthetic fuel on the carbon footprint of heavy-duty vehicles

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As part of the decision at the Paris Climate Conference to limit global warming to below 2°C, the European Union adopted the Climate Change Act, which aims to achieve climate neutrality by 2050. This requires significant reductions in greenhouse gas (GHG) emissions from all sectors, including transport, where reductions are particularly challenging. The transport sector includes civil aviation, rail, shipping and road transport, with road freight playing a dominant role in Germany. Driven by increasing mileage, heavy duty vehicles, which are predominantly fossil fuel powered, are key targets for decarbonisation to meet EU climate targets. They are also important for vehicle manufacturers, as fines can be imposed if fleet targets are not met. The use of lightweight components in heavy duty vehicles and the development and use of renewable fuels are two promising approaches to reducing GHG emissions in this sector in the long term. While weight reduction through the use of lightweight materials reduces fuel consumption and associated emissions, the use of renewable fuels results in lower net GHG emissions to the atmosphere per litre of fuel consumed. Both influence each other in terms of the overall climate impact.

This study examines the environmental life cycle of two innovative hybrid fibre-reinforced plastic lightweight structures in the chassis of heavy duty vehicles (Cradle-to-Grave) and addresses the question of how lightweight construction should be assessed in relation to the introduction of renewable synthetic fuels for use in heavy duty vehicles. In order to investigate the interaction between these two technologies and to assess the influence on the CO2 footprint in a holistic environmental context, different technologies for the production of renewable diesel fuels (Well-to-Tank) are compared. Subsequently, a model will be developed to consistently model the use phase (Tank-to-Wheel) of heavy duty vehicles with mass reduced components and synthetic fuels.

Development of an Integrated Circular Life Cycle Sustainability Assessment Framework for Biobased Wearable E-Textiles: Construction of Life Cycle Inventory and Data Requirements

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E-textiles from sustainable sources aim to enhance environmental sustainability through eco-design, efficient manufacturing, and tailored end-of-life strategies. However, ensuring the sustainability of the e-textile value chain requires a holistic assessment that quantifies environmental, economic, and social impacts. This is particularly challenging due to the absence of clear guidance for conducting a full life cycle sustai-

nability assessment (LCSA) across all three sustainability pillars. Additionally, there is a lack of direction on which input data should be collected, measured, or provided by technology developers for LCSA evaluations.

To address these challenges, this study develops guidelines for constructing life cycle inventories (LCI) and gathering necessary input data tailored to biosourced wearable e-textiles. The proposed integrated framework combines life cycle assessment (LCA) for environmental impacts, life cycle costing (LCC) for economic viability, and social life cycle assessment (S-LCA) for social risks, enabling comprehensive sustainability evaluations. The results from these assessments can be synthesized through multi-criteria optimization to identify optimal trade-offs among sustainability aspects.

The framework also integrates circularity and renewability indicators to assess the synthetic and bio-based components of e-textiles, respectively. By embedding these metrics, the framework provides a more holistic evaluation of a product's contribution to a circular economy.

This framework and its guidelines will be implemented within the European-funded UPWEARS project (ID 101130741), dedicated to advancing resource efficiency and fostering sustainability in the textile industry. This effort will enable the realization of an integrated Circular LCSA Framework, providing actionable insights to quantify LCSA impacts, evaluate circularity, and guide improvements across all sustainability pillars.

Ecodesign applied to cellulose nanofiber production in early stages of development

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Cellulose nanofibrils (CNFs), derived from abundant and renewable cellulosic sources, are innovative and versatile bionanomaterials with several potential applications. This material offers significant sustainability potential, combined with excellent functional properties. The integration of ecodesign principles is essential for determining the most sustainable production pathway for industrial-scale application, considering the low technological readiness level (TRL) of this technology. This study, therefore, aimed to apply ecodesign principles to assess the environmental implications of laboratory-scale CNF production and establish a foundation for scale-up. Environmental sustainability will be evaluated through a cradle-to-gate attributional life cycle assessment (LCA) of CNF production from bleached eucalyptus kraft pulp (BEKP) using two production routes: mechanical ultra-refining (CNF-M) and enzymatic pretreatment followed by mechanical ultra-refining (CNF-E). Life cycle inventory data were obtained from laboratory experiments (primary data), published literature, and databases (secondary data). The Recipe Midpoint impact assessment method was applied to estimate the environmental impacts associated with key process stages. The results identified electricity use for defibrillation (CNF-M) and enzymatic pretreatment (CNF-E) as the leading environmental hotspots in laboratory-scale production. Notably, enzymatic pretreatment without buffer is a crucial feature of the process under study, as it allows scaling up without costly equipment and reduces environmental impact by eliminating buffer chemicals. By incorporating ecodesign principles at a low TRL, this study pinpointed critical enhancements for laboratory-scale processes and investigated feasible approaches for scaling up to higher TRLs. These initiatives were driven by a life cycle perspective and aligned with well-defined environmental goals, fostering the sustainable advancement of CNF production technologies.

Environmental analysis of added value bioproducts for food sector and plastic and materials industry

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The work presents methods used in the environmental assessment of bioproducts of high added value produced from forestry residual streams applying the principles of the circular bioeconomy. The general methodology of the LCA will follow also the following norms developed by the European Standardization Committee CEN/TC 411 WG4: EN 16760:2015, Bio-based products - Life Cycle Assessment; prEN 18027, Bio-based products - Life cycle assessment - Additional requirements and guidelines for comparing the life cycles of bio-based products with their fossil-based equivalents (under approval). For the Life cycle Inventory the guidelines reported in: CEN/TR 16957:2016, Bio-based products - Guidelines for Life Cycle Inventory (LCI) for the End-of-life phase, have to be followed. For the Life Cycle Impact Assessment (LCIA), the set of indicators developed by Karvonen et al. 2017 for the assessment of the sustainability of the forestry bioeconomy are of key importance. These can be integrated with the criteria mentioned in: EN 16751:2016, Bio-based products - Sustainability criteria. Among sustainability criteria also circularity indicators will be taken into account. The circularity indicators for forestry biobased products and processes can be evaluated following the recently published norms ISO 59020 and ISO 59010. The reporting phase can be based on: CEN/TR 17341:2019, Bio-based products - Examples of reporting on sustainability criteria. Results show current projects managed by RISE Processum, among them case studies on:

- bioproducts (plastics and other materials) to be used as components of the automotive sector as per the ANDROID project, funded by Vinnova agency, in which RISE Processum research institute is responsible for LCA activities;

- food ingredients to be used in the production of plant based cheese and kefir, funded by Horizon Europe, coordinated by RISE Processum institute.

Incorporating temporal dynamics of power generation into life cycle assessment of vertical agrivoltaics in Germany

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Agrivoltaics (APV) integrate photovoltaic (PV) systems with agriculture and promise an increase in land efficiency through simultaneous electricity and crop production. While research predominantly focuses on high-mounted APV systems, there is hardly any scientific literature on the ecological assessment of ground-mounted vertical systems. In this study, a life cycle assessment (LCA) of vertical APV on wheat fields in Germany is carried out (product system 1) and compared with the conventional separate production of PV power and wheat (product system 2).

Using the latest manufacturer data, we evaluate innovative heterojunction PV modules that are characterized by high bifaciality, which leads to increased electricity yields in vertical APV. A key feature of this study is the consideration of altered electricity feed-in times resulting from the east-west orientation of vertical modules. Unlike traditional south-facing PV systems that feed in at midday, vertical APV generate electricity during sunrise and sunset, opening potentials for smoothing production profiles and reducing reliance on fossil energy sources during peak morning and evening hours.

To account for these temporal dynamics, we introduce a reference system that balances hourly-resolved footprints of the German electricity mix and supplies wheat from conventional agriculture (product system 3). By simulating the hourly electricity production over a year for APV and conventional PV, we evaluate the feed-in time-specific environmental savings compared to the reference. The comparative analysis reveals that without feed-in time consideration, product system 2 tends to have lower impacts per functional unit.

However, if feed-in times are included, vertical APV offers greater environmental savings across most impact categories.

Our findings underscore the importance of considering electricity feed-in times in environmental assessments of APV systems. This presentation will focus on the methodological approach for integrating temporal dynamics of power generation into LCA of APV and briefly outline selected findings of the comprehensive case study.

Integrating life cycle data into system dynamics models for a dynamic prospective assessment: Benefits for polystyrene chemical recycling

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The transition to a circular plastics economy necessitates the development of alternative end-of-life pathways for plastic products to mitigate harmful plastic waste accumulation and reduce reliance on fossil resources. While mechanical recycling is a well-established technology, significant volumes of plastic waste remain unsuitable for mechanical treatment and are instead incinerated. Chemical recycling has emerged as a complementary technology, offering the potential to process these waste streams and generate high-value chemicals. However, the energy-intensive nature of chemical recycling raises questions about its sustainability and circularity benefits. Comprehensive evaluations, such as prospective life cycle assessments (LCA), are imperative to ensure that investments in emerging technologies are aligned with sustainability goals and to prevent rebound effects that could undermine environmental benefits. However, their static nature often limits their ability to address dynamic factors, such as changing demand, technological advancements, or fluctuating waste flows. To address these limitations, this study explores the integration of life cycle data into System Dynamics (SD) models to enable a dynamic prospective assessment.

This study builds upon a prospective LCA for chemical recycling of polystyrene packaging products considering waste sorting steps, fluidized bed pyrolysis, and upgrading via distillation to the high value chemical styrene. Firstly, it is examined how this data has to be integrated into a SD model to ensure a realistic depiction of the chemical recycling system. Secondly, it is investigated what additional insights can be generated from scenarios in the SD model considering changing demand and technology advancement, such as increased sorting efficiency or pyrolysis yields. By additionally incorporating the process capacities and fluctuating waste steams into the model critical bottlenecks can be identified. Furthermore, SD modeling provides the capability to evaluate the influence of policy interventions, such as subsidies or regulatory incentives, on the overall performance of chemical recycling systems.

Session 3.13: Sustainability & Circularity

Time: Friday, 12/Sept/2025: 2:30pm - 4:00pm
Session Chair: Cécile Bulle, CIRAIG, Canada, Canada
Session Chair: Anna Luthin, Mitsui Chemicals Europe GmbH, Germany

Methodological approaches to modeling circularity using CFF for bio-based feedstocks with multi-life considerations for bio-sourced polymer production

Suchira Sen, Deepa Govindarajan, Suvayan Guha Ray, Ananda Sekar

SABIC, India

Standardization of methodological choices in LCA continues to be an important focus area for the LCA community, to ensure comparability of different LCAs. EU PEF has introduced the use of Circularity Footprint Formula1 for use in End-of-Life modeling impacts of materials. However, the methodology is more than an EOL framework as it applies a multi-life transaction of environmental impacts across lives of a material (transfers burdens and credits across both previous and subsequent life of the material in relation to its current life EOL impacts). Applying CFF to more complex systems offers methodological challenges which should be approached in a consistent manner.

This work focuses on the case of polymer production from Used cooking oil (UCO), which covers multiple lives and multiple value chains. The agricultural and industrial activities linked to edible oil production and their use in hotel industry belongs to the first life of the oil. In the second life, discarded UCO is processed to eventually produce polymer products. These polymers at the end-of-life could be further recycled to start another life of the material, which could be considered the third life. When applying CFF parameters linked to the exchange of upstream impacts (exchanges of first life of the material with the second), one can consider the point of substitution at the level of virgin plastic, or potentially at the level of virgin cooking oil production and each of them require matching the system boundaries (e.g. Cut-off approach). Details of these approaches as well as the impact they may have on the study results will be discussed in this presentation. The impact of modeling approaches, system boundary considerations and the need for careful value judgement of the various CFF parameters will also be discussed.

1. EU PEF: Environmental Footprint Methods - European Commission

Setting Sail for Circular Offshore Wind: MFA, CE, and LCA Insights from Alternative End-of-Life Scenarios for a North Sea Offshore Wind Farm

Célestin Demuytere[1], Gwenny Thomassen[1,2,3], Jo Dewulf[1]

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As Europe accelerates its offshore wind development to meet renewable energy targets and climate goals, the sector faces a critical understudied challenge: managing its End-of-Life (EoL). Yet, this installation upsurge coincides with ageing early offshore wind farms (OWF). With few precedents in decommissioning and no established regulatory frameworks for these complex operations, the risk of valuable material losses is pressing. The rising geopolitical importance of critical material recovery further amplifies the urgency to ensure that large-scale dismantling and resource recovery activities are both efficient and future-proof. Therefore, without clear EoL experience, guidelines and a general lack of primary data, current assessments risk overlooking key circularity opportunities.

This study presents an integrated methodological approach, combining Material Flow Analysis (MFA), circular economy (CE) indicators and Life Cycle Assessment (LCA), applied to a North Sea OWF. To cover

identified variations in offshore processing and design choices, a base case is compared to three alternative scenarios. These scenarios were developed through collaboration with industry experts, recycling contractors and supply chain stakeholders. This ensures they reflect realistic, practice-based strategies rather than theoretical constructs. Examining shifts in component accessibility, processing and waste management strategies, this approach moves beyond conventional static assessments. The research shows that improving data granularity from broad material fractions to subcomponent-level inventories, is crucial for accurately capturing the intricacies of offshore decommissioning.

Ultimately, strategic design decisions, offshore logistics and waste processes can substantially influence long-term sustainability. Integrating MFA, CE and LCA within scenario-based analyses, lays out the way for more informed policy-making, improved industry practices and the development of decision-support tools. Such contributions are vital for aligning offshore wind's growth with Europe's resource resilience, circular economy objectives and environmental responsibilities. By doing so, we ensure that the sector's expansion does not undermine its potential as a key contributor to a sustainable energy future.

Providing a conceptual framework to assess materials with multiple recycling loops in LCA

Inka Hahn[1], Elena Corella-Puertas[1], Yuki Kabe[2], Magnus Fröhling[1]

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The concept of the circular economy is gaining significance due to the necessity for resource- and climate-efficient economies, driven by the predicted climate change, resource scarcity, and regulations at the national and international levels. To achieve this, materials recycling plays a crucial role in bringing raw materials back into the loop and extending the material life cycles. Assessing the environmental impacts of circular systems in Life Cycle Assessment (LCA) requires a consistent quantification of material flows extending beyond the system boundaries of a single product life cycle. This is essential for evaluating and comparing circularity's benefits, especially recycling.

This work focuses on developing an improved LCA allocation framework for multi-loop materials. Although some guidelines and frameworks (e.g. ILCD Handbook, Circular Footprint Formula) give first recommendations for handling multi-loop material recycling in LCA, we have identified various points that are not yet adequately covered, for example:

• Although recycling is considered an End-of-Life scenario at product level, the material that constitutes the product has its life cycle extended, as it will be transferred to another product system. However, life cycle inventories (LCI) capture only exchanges with the ecosphere, so this material transfer is not adequately depicted at LCI level.

• They are lacking in providing consistent allocation procedures when choosing virgin vs. recycled materials in multiple loops.

• The material quality plays a key role in recycling. Several characteristics for multi life stages need to be considered in LCA and are not yet adequately considered (e.g. market conditions, technical restrictions).

Based on this, we propose a conceptual framework for addressing allocation in multiple material recycling loops and provide guidance for the assessment of materials across various material life stages. Applying this framework to a case study on a cascading material use shows the learnings and limitations of the developed methodology.

Towards a Comprehensive Framework for Digital Battery Passports: Addressing Social Data Requirements and Circularity Indicators

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The global battery industry is undergoing a transformation driven by the increasing demand for electric vehicles, which pose various sustainability challenges within battery value chains. Circular strategies can enhance sustainability within battery value chains by extending product life cycles, and minimizing waste through responsible sourcing and End-of-Life (EoL) management. To ensure sustainable circular value chains, it is essential to conduct holistic (environmental and social) sustainability assessments, which can be supported by Digital Battery Passports (DBPs). DBPs facilitate life cycle tracking and the implementation of sustainability strategies, enhance data availability and contribute to a more sustainable and circular economy in the battery industry. While there are first approaches of DBP concepts (e.g., regarding technical and environmental data requirements), they often lack specificity, particularly in relation to the social dimension or which indicators to integrate, e.g., circularity indicators. This research addresses this gap by pursuing two interrelated aims: first, to identify essential social data requirements for a DBP concept, and second, to establish relevant indicators for Circularity Assessment (CA) in the context of EoL lithium-ion batteries (LIBs).

To achieve these aims, a multiple-methods approach is employed, combining literature reviews with workshops involving diverse stakeholders. The first aim focuses on gathering insights into social data requirements of DBPs, emphasizing stakeholder engagement in defining these requirements. The second aim involves identifying and evaluating indicators that can effectively support a CA of EoL LIBs, contributing to the development of a robust DBP concept.

The results include a comprehensive framework that integrates key social data requirements alongside relevant circularity indicators, ultimately contributing to a holistic DBP concept. Future research will refine these social datapoints and indicators and explore how DBPs can facilitate sustainability and CAs through effective data delivery.

Aligning sustainability, circularity and policies to create a monitoring framework for the bioeconomy

Jose Luis Ares Sainz[1], Ana Arias Calvo[1], Nikola Matovic[2], Gumersindo Feijoo[1], Luana Ladu[2], Maria Teresa Moreira[1]

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The European bioeconomy is a promising model for sustainable development. However, its successful implementation requires a comprehensive system for monitoring the sustainability of value chains. In order to address this need, a new monitoring system has been proposed at two levels - governance and operational robustness (system level) and sustainability and circularity analysis (content level) - to effectively assess the sustainability and circularity potential of the bioeconomy based production systems and value chains, also taking into account EU policies and directives. This monitoring framework has harmonized the data available in well-stablished and well-recognized certification schemes, monitoring systems and grey literature, identifying a final set of 142 core sustainability and circularity indicators, grouped into pillars, key areas and sub-areas of concern, and principles. Concretely, 7 key areas of concern were established for the Environmental Pillar, 5 for the Social Pillar and 4 for both the Economic and Circularity Pillars, respectively. To determine the level of compliance, an analysis of alignment with current EU policies and directives was also carried out. With this it has been concluded that circularity and economic sustainability are the areas where greater work is needed to promote efficient, proper and comprehensive sustainability and circularity as-

sessments. The outcomes of this research, as well as the newly proposed monitoring framework, could be seen as a valuable instrument for policy makers, certification bodies and industry stakeholders to enhance and support the development of a more robust bioeconomy and more adequate policies and standards.

This resarch was supported by STAR4BBS (No 101060588) project, funded by the European Commission HORIZON-CL6-2021-ZEROPOLLUTION-01.

Comprehensive Sustainability Assessment of Circular Business Models in the Smartphone Industry – Enabling Holistic Decision-Making Towards Sustainable Practices

Philipp Rittershaus, Venkat Aryan

Fraunhofer UMSICHT, Germany

The smartphone industry exemplifies the divergence between market-driven growth and sustainable resource use, characterized by short product lifecycles, frequent upgrades, and a rising tide of electronic waste. This research examines the economic and environmental impacts of circular business models (CBMs) compared to traditional linear models, using smartphones as a representative product. By conducting a life cycle assessment (LCA), applying the true cost metrics, and evaluating various CBMs, this study delivers a holistic framework for assessing sustainability in this critical sector.

Existing business model research frequently neglects the environmental dimensions of CBMs, focusing instead on operational or financial aspects. This gap is addressed here through a case-by-case trade-off analysis, comparing environmental and economic impacts across different business models. Such refined evaluations empower companies to navigate regulatory landscapes, like the EU's carbon tax policies, and make decisions that align profitability with environmental stewardship.

By integrating environmental and economic assessments, this research supports businesses and equips consumers with the knowledge to make informed purchase decisions. This, in turn, fosters greater adoption and participation in circular economy practices, which are vital for the systemic shift away from linear consumption patterns.

Findings reveal that CBMs, such as refurbishment, and product-as-a-service, offer significant advantages over linear models in terms of reducing waste and extending product lifecycles. However, these benefits are intertwined with economic feasibility, emphasizing the need for joined strategies across sustainability and profitability dimensions. Again, highlighting the need for integrated evaluation frameworks in accessing circular business models.

This study contributes to bridging the theoretical and practical gaps in circular economy research, offering actionable insights for policymakers, businesses, and consumers aiming to drive the transition towards sustainable development in the smartphone sector and beyond.

Enhancing Circularity - Addressing the Diversity of Circularity Indicators for Biobased Systems

Anja Marie Bundgaard, Mette Alberg Mosgaard

Aalborg University, Denmark

A transition to a circular economy has been high on the European political agenda for the last 10 years with the two circular economy action plans. Similarly, the biobased economy should advance to reduce our reliance on finite resource. This has introduced the concept of a circular bioeconomy. Often strategies for a circular economy are divided into a biological cycle and a technical cycles as different strategies and principles are needed. Over the years new circular strategies and principles have emerged to support the circular

bioeconomy.

However, to further support this transition, it is necessary to have indicators which can assess the progress. The aim of this study is therefore to define how to assess the circularity of biobased system by developing a framework of indicators which can supplement LCA. The study provides a comprehensive review of existing scientific literature identifying indicators suitable (and already tested) for assessing the circularity of biobased systems.

The review showed a high diversity in the indicators applied to assess circularity of biobased systems. 120 indicators were identified, 45 at micro level, 31 at meso level and 44 at macro level. One of the only indicators used across several studies were the material circularity indicator (MCI) developed by the Ellen MacArthur Foundation. The MCI was used in eight studies, but specific adaptations were made. This implies that the indicator landscape for biobased system is very diverse and lack standardization which is a challenge for evaluating circularity.

By synthesizing the findings from the review, a framework for circular indicators is proposed. This framework aims to enhance comparability and reliability in circularity assessments for researchers, policymakers, and industry stakeholders. The research is part of the EU-funded LCA4BIO project (n° 101135371).

Classification of Industrial Biobased Systems in the EU as Basis for Sustainability and Circularity Assessment - Suggestions for a Systematic Approach

Muhammad Zeeshan Khan, Gabriele Weber Blaschke, Dr Omar Hijazi

Technical university of munich, Germany

Within the biobased economy, there are manifold potential biobased products (BBPs), processes, feedstocks, and wastes; thus, numerous industrial biobased systems (IBBSs) with diverse value chains exist or are in development. To support comparable assessments and identify the most sustainable and best circular systems, a systematic classification of IBBSs is needed. A comprehensive understanding of the IBBS value chain served as the foundation for developing a structured classification approach. This study develops a harmonised classification framework based on a comprehensive systematic review and multi-criteria decision analysis (MCDA). Numerous classification criteria were comprehensively compiled and evaluated for each element of IBBS. Furthermore, distinctive criteria were organised and developed to include the full spectrum of IBBS with a focus on BBPs. Keeping sustainability assessment in view, three distinct life cycle assessment (LCA) system boundary classifications, namely, value chain consideration, modelling approach and modelling data consideration, are identified. End-of-life (EoL) classification structures the end use of BBPs into useful life phase and end of useful life phase, considering sustainability evaluations, especially separating the substituting or crediting functions or materials through EoL strategies. The proposed harmonisation includes a statistical classification of economic activities (NACE) based classification for BBPs, a platform-based classification for biobased industries, and an origin-based classification criterion for biomass feedstocks. For LCA system boundary and EOL treatment classification, this study recommends applying the framework developed herein. Overall, the proposed harmonised classification framework enables a common foundation for valid and comparable sustainability and circularity assessments of IBBSs.

Session 3.14: Dynamic and Prospective LCA Part II

Time: Friday, 12/Sept/2025: 2:30pm - 4:00pm
Session Chair: Jessica Hanafi, Life Cycle Indonesia, Indonesia
Session Chair: Suzana Ostojic, INaB - RWTH Aachen, Germany

Towards a Generalized Framework for Scaling-Up in Prospective Life Cycle Assessment

Marc Majó, Roland Hischier

Empa, Switzerland

Prospective Life Cycle Assessment (pLCA) plays a critical role evaluating the environmental impacts of emerging technologies from early development stages on, providing a forward-looking framework for the evaluation of the environmental sustainability of these innovations when produced at an industrial level. A key challenge in pLCA is the lack of standardized approaches for scaling such assessments from a lab-scale level to industrial-scale production. While various scaling methods, such as process engineering approximation, simulation, and empirical scaling, have been applied successfully in individual case studies, no comprehensive, generally applicable procedure exists to guide practitioners systematically in such situations. This lack of standardization not only hinders the comparability of studies but also makes each assessment a time-consuming and resource-intensive effort, as unique studies are required.

The objective of our study is the development of a clear and systematic procedure for scaling the production steps within a pLCA study, using lab-scale process information as a foundation for this scaling. To achieve this, a systematic literature review of scaling methodologies applied in pLCA, emphasizing the transition from laboratory to industrial scales, has been established. Advanced AI tools, such as natural language processing (NLP) have been employed in order to identify, classify, and analyze various scaling approaches documented in the literature. Building on these findings, we then established a systematic, engineering-based procedure, representing a clear framework for using lab-scale process data in order to estimate life cycle inventory (LCI) data of future industrial-scale scenarios.

The results of our efforts are clear guidelines allowing to standardize scaling procedures in pLCA, ensuring a more robust, transparent, and better reproducible environmental assessment. The work addresses a critical need for practical tools and methodologies allowing to support sustainability evaluations from early stages of technological development on, bridging in the same time the gap between academic research and industrial applications.

Dynamic prospective life cycle assessment: establishing methodological consistency in evaluating climate change impacts

Susie Ruqun WU, Cécile Bulle, Anne de Bortoli

CIRAIG, Canada

To support informed and future-resilient decision-making, adding a temporal dimension to prospective Life Cycle Assessment (pLCA) integrates temporal and scenario-based assessment into conventional LCA, enabling robust evaluations of emerging technologies under different futures. We propose a framework that harmonizes dynamic and prospective life cycle inventory (dpLCI) with dynamic and prospective life cycle impact assessment (dpLCIA), aligning inventory and characterization factors over consistent temporal and scenario horizons.

We developed three new dynamic and prospective (dp) characterization factors (CFs) focusing on emission metrics on climate change—dp Instantaneous Radiative Forcing (dpIRF), dp Cumulative Radiative Forcing

(dpCRF), and dp Global Warming Potential (dpGWP)—to evaluate climate impacts under varying climate mitigation scenarios from the IPCC CMIP6 database. We then applied the new framework to future garbage trucks—either electric or diesel powertrain—driven in Quebec, Canada, across three mainstream transition scenarios (SSP1-RCP1.9, SSP2-RCP4.5, SSP5-RCP8.5) and future years (2030, 2040, 2050).

The new dpCFs reveals a divergence between absolute metrics (dpIRF/dpCRF) and relative metrics (dpGWP), as dpIRF/dpCRF receive highest CFs under a lowest-carbon scenario (i.e. SSP1-RCP1.9). The case study results suggest that deploying low-carbon technologies (e.g., advanced batteries for battery electric vehicle and synthetic diesel with carbon capture for diesel powertrain) in a low-carbon scenario SSP1-RCP1.9 maximizes technologies' potential from inventory stage to reduce climate impacts. Even though the absolute metrics have downplayed these benefits by assigning higher CFs to emissions in a low-carbon future.

The findings advocate for the adoption of dpLCA frameworks to prevent lock-in effects so that policymakers can evaluate the long-term impacts of current decisions. This study highlights the critical need for methodological consistency in dpLCA to inform sustainable technology transitions.

Energizing Life Cycle Assessment: A Dynamic Approach to Europe's Electricity Mix

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The time-intensive process of collecting data and updating life cycle inventory (LCI) databases leads to a delay between the represented data and the real-world conditions at the time of release, wherefore contemporary and prospective Life Cycle Assessments (LCAs) base on LCIs that represent bygone points in past. This delay undermines the accuracy of LCAs – particularly for products and processes with dynamically changing requirements. Companies, for example, typically report their GHG emissions using current-year emission factors for scope 1 and 2 but base their scope 3 typically on retrospective LCIs, creating a temporal mismatch. Similarly, EPDs and LCAs, even when based on temporally representative primary data for the foreground system, still depend heavily on temporally mismatching LCI databases. In this work, we take the first step toward creating a truly contemporary LCI database by updating Germany's rapidly changing electricity mix datasets and their dependent inventories in ecoinvent. We present a Python-based framework "CHARGE", that updates ecoinvent datasets using real-time data. Thus, shifting LCAs from relying on static, annualized, and outdated electricity data towards up-to-date real-world data. This provides a scalable open-source solution for industries and researchers seeking precise and actionable LCA results for sustainable innovation. Moreover, the intermittency of renewables leads to strong deviations of diurnal and seasonal impacts, which demonstrates the benefits of using dynamic electricity data compared to static annual averages for driving sustainable production and consumptions patters and devising actionable and optimized decarbonization strategies. The results demonstrate the importance of eliminating time lag between data collection and database release to achieve temporal homogeneity between foreground and background systems. This contribution invites discussions on advancing LCA methodologies towards truly contemporary LCI databases and the benefits this would bring to further accelerating decarbonization.

Integrated Prospective Environmental and Economic Assessment Framework for Emergent Technology Development: A Case Study of Steel Slags Carbonation as a Carbon Capture, Utilization and Storage Material

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Emergent technologies are typically characterized to be at lower technology readiness levels (TRL), which means that there is limited information available about their life cycle inventory, significant uncertainties in the data that are available, and unknown effects of the economy-of-scale. These challenges complicate the assessment of the environmental and economic impacts of emergent technologies. However, being at a low TRL also provides an opportunity for flexibility and improvement in both the technology's efficacy and its environmental and economic potential, compared to more mature technologies. Therefore, it is crucial to quantify the environmental and economic impacts at lower TRL stages in order to identify hotspots and guide improvements in the technology. This study aims to propose an integrated framework for prospective environmental and economic assessment of emerging technologies. The framework includes a multi-criteria optimization assessment (MCOA) to determine the best scenarios based on trade-offs between environmental and economic impacts, calculated through the life cycle assessment (LCA) and life cycle costing (LCC), respectively. Additionally, prospective LCA (pLCA) is used as a scenario analysis tool to identify key technological parameters that require further research to reduce global warming potential (GWP) and improve environmental sustainability of the assessed emergent technology. A case study on steel slags mineral carbonation, as an emergent carbon capture, utilization, and storage material, demonstrates the implementation of this framework. The results of the framework identified the optimal carbonation conditions for steel slags, depending on environmental and economic requirements. The results of the implementation of the framework also estimated the ideal duration for carbonation and highlighted improving carbonation efficiency as a key technological parameter to reduce the GWP of the process. This approach offers valuable insights for advancing the development of emergent technologies in a more environmentally and economically sustainable direction.

The prospective life cycle assessment of on-site waste-to-marine fuel valorization in cement plants: the impacts of learning effects

Daniel Fozer, Mikolaj Owsianiak

Technical University of Denmark, Denmark

Cement production generates approximately 8% of global CO2-equivalent impacts, underscoring the need for novel decarbonization solutions. This study employs a comprehensive prospective life cycle assessment (pLCA) framework to evaluate on-site waste-to-marine fuel valorization in cement plants at early development stages, focusing on integrating learning effects to project improvements in the foreground system and addressing both temporal and spatial dimensions. The replacement of fossil fuels is modelled with solid recovered fuel (SRF), waste pyrolysis-derived co-products, and renewable marine fuel production, analyzing environmental impacts between 2025 and 2050 across multiple shared socioeconomic pathways (SSP1, SSP2) combined with a representative concentration pathway (SSP2-RCP1.9). The prospective results indicate that the carbon footprint of clinker production can be reduced by up to 32% by 2050 due to projected technological progress translated into environmental gains. By incorporating learning-effects-driven dynamic foreground data in the pLCA and harmonizing the progress with the

background system, the findings highlight the important role of learning rates quantification in creating sustainable-by-design trajectories and driving reductions in environmental impacts while identifying potential burden-shifting tendencies and improving the accuracy of prospective environmental assessments.

The prospective assessment provides actionable insights for integrating circular waste valorization pathways into cement production, fostering systemic decarbonization and enhancing the temporal relevance of sustainability assessments, and emphasizes the importance of addressing uncertainties in technological efficiency and system dynamics to avoid lock-in effects and ensure long-term sustainability at early technology design stages.

Incorporating temporal dynamics of power generation into life cycle assessment of vertical agrivoltaics in Germany

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Agrivoltaics (APV) integrate photovoltaic (PV) systems with agriculture and promise an increase in land efficiency through simultaneous electricity and crop production. While research predominantly focuses on high-mounted APV systems, there is hardly any scientific literature on the ecological assessment of ground-mounted vertical systems. In this study, a life cycle assessment (LCA) of vertical APV on wheat fields in Germany is carried out (product system 1) and compared with the conventional separate production of PV power and wheat (product system 2).

Using the latest manufacturer data, we evaluate innovative heterojunction PV modules that are characterized by high bifaciality, which leads to increased electricity yields in vertical APV. A key feature of this study is the consideration of altered electricity feed-in times resulting from the east-west orientation of vertical modules. Unlike traditional south-facing PV systems that feed in at midday, vertical APV generate electricity during sunrise and sunset, opening potentials for smoothing production profiles and reducing reliance on fossil energy sources during peak morning and evening hours.

To account for these temporal dynamics, we introduce a reference system that balances hourly-resolved footprints of the German electricity mix and supplies wheat from conventional agriculture (product system 3). By simulating the hourly electricity production over a year for APV and conventional PV, we evaluate the feed-in time-specific environmental savings compared to the reference. The comparative analysis reveals that without feed-in time consideration, product system 2 tends to have lower impacts per functional unit. However, if feed-in times are included, vertical APV offers greater environmental savings across most impact categories.

Our findings underscore the importance of considering electricity feed-in times in environmental assessments of APV systems. This presentation will focus on the methodological approach for integrating temporal dynamics of power generation into LCA of APV and briefly outline selected findings of the comprehensive case study.

Spatialized and Prospective LCA of Agrivoltaism in the Mediterranean basin under Climate Change

Pierre Jouannais[1,2], Lia Rapella[3], Philippe Drobinksi[3], Nicolas Viovy[4], Mélanie Douziech[5], Mathilde Marchand[2]

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Mediterranean agriculture will face significant challenges from climate change throughout the 21st century, necessitating adaptation to sustain production. Without such measures, reduced efficiency and yields will further increase agriculture's environmental footprint to maintain output levels. Among the options for adaptation and mitigation, agrivoltaics—the integration on the same land of photovoltaic energy production and crop cultivation—offers a promising solution by mitigating climate impacts on crops while promoting renewable energy production.

However, the environmental performance of agrivoltaic systems depends on complex interactions among technological, agronomic, and meteorological factors, all of which are expected to evolve. Anticipating these systems' future performances is essential to identify contexts and scenarios where agrivoltaics maximize environmental benefits. Such projection also helps prevent suboptimal deployment, where conventional photovoltaic and agricultural systems might outperform agrivoltaics.

Our study thus supports decision-making by conducting a prospective, consequential life cycle assessment (LCA) of agrivoltaics, whether driven by crop or energy demand. We integrate a parameterized LCA model with prospective databases using PREMISE and simulate yields and environmental flows with the ORCHIDEE land surface model, tailored for agrivoltaic and conventional systems. The analysis focuses on the Mediterranean coasts of France, Spain, and Italy, considering local soil carbon and water dynamics. Substantial attention is given to addressing the uncertainty and the sensitivity of the results in relation to the three components of the model, i.e., foreground, background and land surface model.

Our work thus provides an insightful mapping of where, when, to what extent and under which scenarios agrivoltaic impacts outperform the conventional ones by studying a large scope of possibilities for socio-economic patways (SSP), climate trajectories, technological and methodological choices. This comprehensive approach provides actionable insights for planning agrivoltaic deployment under diverse scenarios for the 21st century.

Coupling LCA And Dynamic MFA: A Literature Analysis

Alexis Boutin[1,2,3], Anne Ventura[1], Franck Michaud[2], Cyrille François[4]

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A combined implementation of Life Cycle Assessment (LCA) and Material Flow Analysis (MFA) is needed to represent a system with its flows, stocks and their related transition dynamics and also assess environmental impacts related to system's flows with a full LC perspective at different scales: production line, company, territory, etc. However, this coupling is subject to several methodological issues that first need to be overcame:

LCA of products (which is the traditional LCA, and will be referred as LCA hereafter) and MFA don't have the same scopes, implying different system boundaries. While MFA has a wide view on a system with all related products implied in the studied territory, LCA focuses on a unique product (i.e. the reference flow) around which the system is built, also taking into account processes that took place outside the studied territory but implied in the LC. As a consequence, links between coproducts have been cut, or substituted, in LCA databases, preventing from considering an industrial process entirely.

Based on that assumption, the traditional LCA calculation routine has been built on the basis of matrix

inversion (Heijungs and Suh, 2002). The representation of the problem in the form of matrices provides a concise formulation, but restricts to square technological matrices (to be inversible), and so is unable to consider multioutput processes. Taking temporality into consideration is necessary when transition scenarios are considered. The evolution of flows and stocks of material across the time are considered in dynamic MFA, but stocks are completely absent in LCA.

As some couplings have already been led (Barkhausen et al., 2023), a bibliographic review will be presented to position those issues in the literature and identify if they are addressed and how to properly couple LCA and MFA in a context of territorial transition.

Session 3.15: Data Creation & Exchange Tools: Transparency First

Time: Friday, 12/Sept/2025: 2:30pm - 4:00pm
Session Chair: Stephan Pfister, ETH Zurich, Switzerland
Session Chair: Emilia Moreno Ruiz, ecoinvent, Switzerland

EcoOpt1iPack: OnlineLCA for Automated LCA Calculations and Transparent Assessments of Plastic Packaging Solutions

Anna Kerps[1], **Friedrich Halstenberg**[2]

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LCA has emerged as a cornerstone methodology in upcoming regulations and industry initiatives, bringing attention to challenges in data quality and transparency. Despite standardized approaches, subjectivity persists in practitioners' choices, introducing variability in LCA outcomes that undermines reliability and comparability. This study showcases EcoOptiPack, an innovative online LCA tool that serves as a strategic instrument for managing fast-track assessments of plastic packaging while ensuring transparency and facilitating the exchange of LCA information. The tool enables both manual and automated assessments using a Digital Product Passport (DPP) for plastic packaging.

To prove the robustness and verify the tool, seventeen LCA practitioners of varying expertise independently conducted an LCA for a fictitious three-component plastic packaging using identical instructions. Practitioners received all necessary data to map out the LCA, but key decision aspects were intentionally left open, including software choice, database selection, handling of multifunctionality, and impact assessment methods. The resulting variability in their assessments highlighted significant uncertainties attributable to individual subjective choices. Subsequently, the same LCA was recalculated using the newly developed EcoOptiPack tool, based on the pre-defined LCA model for plastic packaging. By pre-defining the assessment process, providing consistent modeling, and utilizing open-access data through the DPP and standardized impact assessment methods, the tool significantly reduces uncertainties arising from individual practitioner choices. It even enables non-LCA experts to conduct LCAs of plastic packaging solutions confidently.

Our findings position digital tools like EcoOptiPack as vital strategies for LCA calculations while fostering transparency through open-access DPP information. The tool contributes to enabling companies to make sustainable choices and supports the LCA community in overcoming limitations of current practice by improving data creation, management, and exchange. By addressing variability and enhancing data transparency, EcoOptiPack aligns with the session's objectives to explore strategies and tools that empower companies in their data-related needs.

Assessing modelling uncertainty at different database aggregation levels - a comparative study

Elisabetta Pigni[1], **Ning An**[2], **Serena Righi**[1,3], **Diego Marazza**[1,3], **Massimo Pizzol**[2]

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This study compares the performance of two background databases and focuses on the uncertainties of LCA results. The input-output database EXIOBASE and the process-based database ecoinvent were used as background systems to assess the potential medium- and long-term environmental impacts of an emerging sewage sludge exploitation technology (Horizon 2020 project ToSynFuel – G.A. 745749). While in ecoinvent the uncertainty is estimated by the developers using the pedigree matrix approach, the uncertainty of EXIOBASE was not provided by the database developers, and only experimental studies have attempted to estimate it. We thus estimate the data uncertainty of EXIOBASE under different assumptions and degrees of complexity, including the use of the pedigree matrix approach – so that it could be directly compared with ecoinvent. Furthermore, we use the pedigree matrix approach to estimate the model uncertainty introduced when using ecoinvent datasets and EXIOBASE datasets respectively as background matches the foreground materials and energy inputs of the ToSynFuel technology. We then create a python script using the Brightway library and apply stochastic error propagation via Monte Carlo Simulations using both databases to obtain the range of impact scores. For the case under analysis, the range of scores obtained using ecoinvent is lower than the range obtained when using EXIOBASE – given the estimated uncertainties. This is due to both a model uncertainty when matching specific inputs with aggregated EXIOBASE data and an intrinsic EXIOBASE data uncertainty. Although more case studies should be analysed to confirm the general validity of this result, our work shows that addressing the uncertainty of LCA databases allows to understand the implications of database choices and dataset matches. This study provides useful insights about EXIOBASE behaviour when used as a background database.

Breaking Down Complexity: A Modular, Model-Driven Life Cycle Data Management Tool for Biofuels and Bioenergy

Oliver Hurtig, Romain Besseau, Anne Bouter, Nicolae Scarlat

European Commission Joint Research Center, Italy

The increasing reliance on Life Cycle Assessment (LCA) in EU legislation and policy decisions underscores the need for accurate, reliable, flexible and transparent Life Cycle Inventory (LCI) data. However, traditional databases often suffer from limitations such as data redundancy, inconsistencies, and lack of transparency. Using standard LCA tools often implies relatively static inventories and difficulties in making complex parameter calculations or maintaining a database up to date. To address these challenges, we present a novel approach to LCI database development, exemplified by the revamped Joint Research Centre (JRC) database for bioenergy pathways.

Our solution, based on concepts from tools like Hestia and Depart de Sentier, leverages a Python-based tool that breaks down the complexity of LCI data collection by employing small, modular models for each stage of the life cycle to output an openLCA database. The guiding principle is to use different tools for what they do best: tabular data files for data, python for processing and complex logic, and openLCA or other LCA tools for life cycle analysis and impact assessment. This approach enables data to be inserted only once and at the right level, reducing potential errors and increasing efficiency. The modular design allows for easy updates, sharing, and integration of new data sources, ensuring the database remains transparent, reusable, and future-proof. This approach also facilitates the treatment of co-products using different methods, eliminating the need for database variants. It also allows for very flexible sensitivity and scenario analysis.

How unsuitable data and data choices can negatively influence reliability and costs of decarbonization efforts, supplier choices and sustainability approaches in companies

Martin Baitz, Tim Becker, Cecilia Makishi Colodel, Magnus Piotrowski, Matthias Rudolf, Lionel Thellier Mercier

Sphera Solutions GmbH, Germany

If reliable quality LCA results are aimed, certain data can be unsuitable due to fundamental issues:

a) data may not live up to the needs to support quality results (induced by data provider) or

b) choices of data may not appropriate to support the needed quality (induced by user).

International standards and sectors initiatives lack proper data quality definitions. New data concepts that are brought to market or made available by universities or governments; imposing considerable risks of misuse or poor results. Poor results may relatively harmless in academic applications, but have significant financial, reputational and legal consequences in industry; e.g. misinformation of customers and regulators, failure to meet reduction targets, loss of trust, ineffective investments.

To prevent/mitigate risks under "a)" data concepts must have proven practical relevance and need continuous confirmation. Cleverly marketed (new/incompletely defined) data concepts require to check data frameworks, especially with regard to "technical quality" of data.

To mitigate risks under "b)" users must act and inform themselves about data background and its "fitness for purpose".

We discuss following risks:

- specific data vs. statistical and market mediated Input -Output data

- unsuitable modelling of regionalisation and technology

- gap closing issues with "worst case approach"

- avoiding green washing without obstruct decarbonisation

- role of AI and issues with cloned data

- how data age is misinterpreted

All stakeholders in the supply chain, incl. the customer and the policy makers expect reliable results based on real differences in technology and supply chain.

LCA data is at least supportive, often compulsory : see Chemicals Regulations, Extended Producer Responsibility, ESG, Product Eco-design; EoL Vehicle and Packaging Regulation, CSRD, Conflict Minerals, ESPR and Carbon Border Adjustment Mechanism).

Virtual differences by poorly defined, misunderstood or unsuitable data (qualities) must be identified and avoided to minimize wrong consequences.

Taiwan ICT Production Value Chain Trusted Emission Data Collection and Exchange Mechanism based on the Partnership for Carbon Transparency (PACT) and Local-based Emission Factor Data Pool

Calvin Tsai[1], Yen-Haw Chen[2], Evie Lin[1], Ying Fen{Wendy} Chen[2]

[1]Institute for Information Industry(III), Taiwan; [2]Taiwan Institute of Economic Research (TIER), Taiwan

As global regulatory landscapes evolve rapidly, companies face increasing pressure to enhance the accuracy and compliance efforts of their sustainability reporting. And consumers are increasingly conscious of the environmental impact of the products and services they're using.

Companies are urgently seeking high-quality data solutions responding to their green claims for carbon neutral product to foster better understanding of emissions data across their product value chains. Taiwan is a recognized as the key partners in the global supply chain of ICT industry, and significantly need the innovative solutions of supporting the companies' green goods and the greening value chain.

However, many companies lack sufficiently granular and accurate primary product-level data for carbon accounting and the consistent guidance for data sharing and exchange across value chains. It not only results in a lack of transparency across value chains, but discounts the consumers' contribution for green consumption. The average data from secondary emission factor databases often provide non-specific-enough data which hardly meets companies' needs of data accuracy.

Therefore, our team—comprising III and TIER, the leading standardization body of Taiwan's ICT industry and the government's key think tank—has proposed a comprehensive solution. We have introduced the Product Carbon Footprint (PCF) Guideline to standardize PCF calculations across Taiwan's ICT sector, enhancing the quality of primary data. Additionally, we developed a free and interconnected framework that includes "Data Collection," "Data Exchange API & Data Model Adaptation," "Data Transfer," and "Digital Sustainability Cloud (DSC) Services." As an extension of PACT, this initiative establishes a baseline for comparable PCF data exchange, enabling companies to share data more efficiently and fostering greater sustainability across the industry.

Meanwhile, through the framework of Taiwan-based emission factor data pool of ICT products, the consistent and accurate basis of carbon accounting methodology for products and services could be fundamentally set up.

From Plow to Pixel: An Analysis of Supply Chain Transparency and Traceability in Agrifood and Implications for Digital Product Passports

Kartik Chawla, Theodor {T.C} Chirvasuta, Sjoerd {S.G.J.} Rongen

TNO, The Netherlands

The demand for transparency in global supply chains has surged in recent years, driven by consumer expectations and regulatory requirements. The European Union's Digital Product Passport (DPP) initiative, outlined in the Ecodesign for Sustainable Products Regulation (EU) 2024/1781 (ESPR), was introduced to address this demand, particularly in relation to enhancing sustainability and facilitating circular economy goals by providing comprehensive, accessible, and interoperable product information.

Transparency and traceability systems are, however, not a new concept, particularly in the agrifood industry. Existing systems like TRACES, FairTrade, GS1 EPCIS, OpenFoodFacts, and Pluotos serve as critical tools in traceability, transparency, compliance, and sustainability. This raises two key questions: What challenges do existing transparency and traceability systems face in the agrifood sector, and what lessons can they offer for the design of DPP-based transparency and traceability systems?

To answer these questions, we conduct an exploratory, inductive case study of five diverse systems: GS1 EPCIS, FairTrade, Ploutos, OpenFoodFacts, and TRACES. We study the design choices implemented in, benefits offered by, and obstacles encountered by each of these systems to derive insights into the limita-

tions that they face in implementing effective transparency across the supply chain. We adopt a qualitative document analysis method for this case study, supported by thematic analysis, to identify the design principles they can offer for the design of future transparency and traceability systems, including DPP-based systems.

Preliminary findings highlight that while the individual systems are useful, they do not provide a comprehensive overview of the supply chain by themselves. Every stage of the supply chain is likely to have different stakeholders, requirements and incentives. A complex supply chain can therefore require multiple transparency and traceability systems, each customised for their targeted stakeholders. However, achieving holistic transparency and traceability requires careful organisational and ecosystem coordination, technical interoperability, and sustainable maintenance.

Mimicking financial accounting and reporting principles to overcome obstacle to data sharing for LCA

Tomas Vilhelm Rydberg, Benjamin Donovan, Henrik Johansson

IVL Swedish Environmental Research Institute, Sweden

Financial accounting, reporting and transactions in value chains has been developed over many decades, thus leading to a balance between transparency and confidentiality.

One of the obstacles of LCI/LCA data sharing along value chains and to the broader stakeholder community is the insufficient confidentiality related to the need for detail in LCI information, where also the provisions for data accuracy often requested in LCA context leads to a suspicion among industry operators to share their data as this could put them in an unfavourable negotiation position because the environmental profile could be used to calculate backwards the cost of the operator to produce the product. Or a least this is the fear.

The problem at hand can be described as being that the environmental performance requested when asking for data for LCA, is a type of cost statement for a product. And the problem could be at least partly overcome, if instead the communicated environmental performance (or profile) would be information corresponding to the price of the product.

The presentation will present and discuss the benefits and other implications of applying the “price analogy” to communicating environmental performance data, rather than applying a “cost analogy”, which is the current paradigm in LCA.

FastCrop Footprint: Quick, transparent and accurate environmental footprint calculations of crop production

Eline Susanne Disselhorst, Wilhelmina Meike Marieke Hopman, Nicolo Braconi

Mérieux Nutrisciences | Blonk, The Netherlands

Measuring and improving environmental sustainability has never been more critical, driven by the urgency to fight climate change and regulatory pressures such as CSRD. However, businesses face challenges in structural large-scale collection of supply chain specific data and gaining meaningful insights into the environmental footprint of their upstream operations. That’s where the digital solution FastCrop Footprint™ steps in.

FastCrop Footprint™ is a web-based solution that provides instant product and supplier specific insights into the environmental impact of crops in line with the latest international footprinting standards. Supply chain specific primary data are collected via a user-friendly online data form and complemented with secondary data from LCA databases such as Agri-Footprint. This innovative modelling approach, which overwrites the most relevant data points by primary data, minimizes data collection efforts in the supply

chain by producers, while ensuring accuracy, traceability and credibility. The FastCrop Footprint™ dashboard supports easy validation of results to ensure high quality primary data input and facilitates data monitoring across products, locations, and years. The tool gives visual representations of contribution analysis and environmental impacts. These can be securely shared with primary producers and their stakeholders; such as retailers and food processors. Environmental footprint results can be recalculated to stay up-to-date with the latest international footprinting standards. The instant and actionable results can be used to develop effective reduction strategies, driving sustainability and business value.

Monitoring environmental footprints is highly relevant but challenging due to evolving guidelines and supply chains. There is a need for user-friendly large-scale primary data collection with limited data collection efforts. The innovative modelling approach in FastCrop Footprint™ is based on high quality secondary data in which the most relevant data points are replaced by primary data to get insight in accurate product-specific environmental footprints and the total footprint of cultivation at the production site.

Extrapolation of environmental impacts for electronic products

Lika Kvaratskhelia, Kristína Germano Nunes, Cedric Bardenhagen, Rob Moody, Maike Seifert, Filipe Sundfeld Veloso

Siemens AG, Deutschland

The increasing demand for Environmental Product Declarations (EPDs) requires companies to efficiently perform Life Cycle Assessments (LCAs) for large product portfolios, a task often constrained by resource intensity. Existing scaling methodologies for environmental impacts often rely on a simple mass scaling. Those approaches lack accuracy especially for electronic products and components. This study presents a software-aided multiparametric scaling approach. Key steps include i) data preparation and automation ii) k-means clustering of product portfolio iii) matching algorithm iv) regression analysis v) quality assurance. In this study, the methodology is validated through the application on the homogeneous product family of servo drives.

Session 3.16: LCM's Future: Collaboration, Innovation & Impact

Time: Friday, 12/Sept/2025: 2:30pm - 4:00pm

Session Chair: Philip Strothmann, Forum for Sustainability through Life Cycle Innovation e.V., Germany

Session Chair: Anna Wikström, Swedish Life Cycle Center/Chalmers University of Technology, Sweden

LCARSIN: The UK LCA Regulatory Science and Innovation Network

Rachael Rothman, Stuart Walker

University of Sheffield, United Kingdom

The Life Cycle Assessment Regulatory Science and Innovation Network is funded by

Innovate UK, led by the University of Sheffield and including UK Universities, industrial partners, regulators and policymakers, non-governmental organisations and trade bodies.

The network was formed in response to the needs of the UK materials supply chain and Foundation Industries. During the discovery phase, the survey showed 93% felt that a network on LCA for regulatory science would definitely be useful, with 7% saying possibly and they would need to hear more.

Now in implementation phase, the network encourages harmonisation in the use of LCA in policymaking as the UK moves towards Net Zero. We aim to understand regulatory needs to achieve a more sustainable future and develop solutions through knowledge sharing, research and training.

On behalf of the LCARSIN leadership team, this presentation will summarise progress made during the first year. We will highlight the success of the network (including bringing together much of the UK LCA community, contributing to the development of international standards, co-developing objectives with regulators and successfully gaining funding for a second phase), as well as challenges faced and solutions developed.

LCARSIN operates through three key routes: Working Groups, Special Interest Groups, and Signposting. Working Groups comprise subject matter experts and have been established to answer key questions in five subject areas. These working groups are now in operation. Special Interest Groups combine experts with those looking to learn and emphasise knowledge transfer. The network has already enabled the transfer of knowledge and experience within and across industry sectors. The network is connected to other national and international groups and networks, across both LCA specific and industrial focussed groups.

As LCARSIN continues to grow, we look forward to presenting the network, engaging with other networks, establishing collaboration and sharing our successes and challenges.

FSLCI - A community approach to accelerate Life Cycle Innovation globally

Philip Strothmann, Guido Sonnemann, Martina Prox, Sanjeevan Bajaj

Forum for Sustainability through Life Cycle Innovation e.V., Germany

Over the past two decades, the Life Cycle Community has made significant progress in achieving methodological improvements and building capacity to conduct life cycle assessment studies and generating inventory data sets. Now, with Life Cycle Assessment (LCA) and Management (LCM) gaining more and more attention among decision-makers in industry and governments, demand for life cycle expertise around the world is also increasing.

While universities are gradually introducing more classes to teach LCA and thereby equip new generations with much-needed skills, life cycle networks and communities often offer a space to learn from each other, run programs to foster competence development and facilitate collaboration. While some of these networ-

ks focus on local or national activities, others take a more global perspective. To this end especially the Forum for Sustainability through Life Cycle Innovation e.V. (FSLCI) has become a key stakeholder since its launch in 2015.

Established as a membership-driven global community organization, the FSLCI nowadays provides a home for the life cycle community, acts as a central information and networking hub, organizes educational programs and has put a spotlight on relevant issues for the community to address, such as marine litter within LCA.

The presentation will provide an overview of the recent work that the FSLCI has carried out to further support the uptake of LCA and LCM and outline its programmatic approach for the next years to further global coordination, collaboration and communication to advance life cycle innovation. The presentation will also highlight insights from a recent survey on key issues relevant to the wider life cycle community to showcase which issues require attention and need to be addressed in the future.

Reviving collaboration for sustainability in Francophone region: the role of LCM2LOOP in advancing LCM

Christian Traisnel[1], Naeem Adibi[1,2], Laura Devisme[1,2]

[1]LCM2LOOP association, France; [2]WeLOOP, France

The LCM2LOOP association, established in 2021, was created to revive the avniR platform, initially launched in 2009 to advance Life Cycle Assessment (LCA). Managed through CD2E until 2017, the platform supported industries and hosted an annual LCA conference, fostering collaboration and knowledge sharing in the Francophone region. To address the void left by its discontinuation, LCM2LOOP was founded to re-establish vital spaces for exchange and innovation.

The association's inaugural initiative was organizing the LCM 2023 conference and MCV 2024 in Lille, leveraging its expertise to reconnect with national and international stakeholders. Over the last decade, LCA has transitioned from a specialized research tool to an essential resource for economic sectors, businesses, R&D teams, and funders. It is now instrumental in assessing and addressing environmental impacts across value chains. LCM2LOOP's integration into the French PEXE network further extends the reach of LCM, promoting its adoption and supporting consulting firms proficient in its application.

Strategic Objectives:

1. Enhancing LCA Methodologies: Collaborate with experts to refine tools, improve databases, and balance simplification with methodological rigor.
2. Driving Industry Adoption: Use LCA as a lever for sector-wide advancement, addressing value chain impacts while adapting to technological and economic changes.
3. Engaging SMEs and Mid-Sized Companies: Simplify LCA approaches, build awareness, and promote collaboration among consulting firms to support these pivotal economic players.
4. Empowering Key Influencers: Identify and educate prescribers within sectors to integrate LCA into their frameworks, amplifying its role in environmental transformation.

LCM2LOOP builds on its legacy while adapting to emerging challenges, aiming to make LCM a mainstream tool for decision-makers. This abstract invites participants to explore future collaborations and share best practices to advance sustainable development.

Automating Life Cycle Assessment and Environmental Product Declaration Generation Through Cross-Business and IT Collaboration

Tanvi Sharma, Jens-Christian Holst, Maike Seifert, Timon Baldow

Siemens AG, Germany

Life Cycle Assessment (LCA) and Environmental Product Declarations (EPDs) are vital tools for quantifying the environmental impacts of products and meeting sustainability goals. Traditional LCA processes are often time-intensive and dependent on manual data gathering, which can limit scalability and responsiveness to market demands. This project demonstrates an innovative approach to automating LCA and EPD workflows through seamless collaboration between business units and IT.

The automation solution integrates data from multiple sources, starting with the automatic upload of Bills of Materials (BOM) based on manufacturing part numbers. Complementary data streams, including distribution logistics, use phase parameters, and end-of-life (EoL) scenarios, are systematically fed into the in-house LCA tool called the Green Digital Twin (GDT) via Snowflake Data Cloud. Once the input data is consolidated, the tool calculates the LCA results in compliance with established standards (EPD Type III). These results are then formatted into machine-readable EPD data (in ECLASS format) and automatically transferred to customer-facing web platforms and e-commerce systems, ensuring transparent communication of environmental information.

This end-to-end automation significantly reduces the time and effort required for LCA generation while enhancing data accuracy and consistency. The project's success highlights the potential of cross-disciplinary collaboration and digital integration to streamline sustainability practices, and meet regulatory requirements.

Electricity modelling for "zero-emission" vehicles life cycle assessment (LCA): the TranSensus LCA European research project holistic approach

Anne Françoise Grau[1], Marie Pinochet[2]

1EDF, France; 2Univ. Grenoble Alpes, CEA, Liten, DEHT, 38000 Grenoble, France

TranSensus LCA (TSLCA) is a collaborative research project funded by the European Union gathering 41 entities, coming from both industry and research institutes. One of its mains objectives is to develop harmonised guidelines for "zero-emission" vehicles LCA, which can be used for three different types of LCAs: product level, fleet level and prospective LCAs. As such, these guidelines tackle, for all three types of LCAs, on-site electricity production as well as electricity consumption for the vehicle manufacturing phase, its use and end-of-life phases. Electricity modelling is an intensely debated subject in the LCA community, yet, thanks to the consensus building process of TSLCA and the wide range of expertise among beneficiaries, it was possible to come to an agreed methodology.

The following electricity consumption modelling approaches were discussed during the project:

for the manufacturing phase of product and fleet level LCAs:

- a location-based approach,
- a 100% market-based approach with safeguards,
- and a mixed approach that combines elements from both approaches above,
- for the life cycle phases located in the future (i.e., use and end-of-life phases) and prospective LCAs:
- a "dynamic" modelling approach,
- and a "static" modelling approach.

These possibilities were voted upon and approaches reaching a 2/3 majority acceptance were included in

the final TSLCA guidelines.

Similarly, specific guidelines were derived for on-site electricity production when it was deemed relevant in life-cycle phases and according to the type of LCA.

Whatever the approach chosen for electricity modelling, the TSLCA project requires that the same approach be used in all instances of explicitly comparative LCAs, which are aimed at making "comparative assertions", as defined by ISO 14044. Therefore, electricity modelling choices must be justified and documented to be transparent to the recipients of the TSLCA LCA reports.

Session 3.17: Using LCSA for Industry Decision-Making Part II

Time: Friday, 12/Sept/2025: 2:30pm - 4:00pm
Session Chair: Nils Jäger, thyssenkrupp Steel Europe AG, Germany
Session Chair: Julian Suer, thyssenkrupp Steel Europe AG, Germany

Sustainability Assessment in Industrial R&D: Challenges and Contributions to Decision-Making

Denise Ott, Marvin Gornik, Shashank Goyal, Mary Osorio

EurA AG, Germany

As industry faces increasing pressure to deal more intensively with the environmental and social aspects of its activities, sustainability assessments have become crucial tools for decision-making and product promotion. At the same time, the regulatory framework for sustainability reporting is contributing to a more intensive examination of entrepreneurial business models and their resilience, for example with regard to climate change, resource bottlenecks or skilled labor shortages.

The use of life cycle sustainability assessment methods is not only supported through various policies and legislation but is nowadays a prerequisite for the implementation of R&D projects at European level. This is not least due to the fact that there is incredible potential for improvement, especially in the configuration phase of a process or product.

However, managing the complexity of evolving policies and regulations is a major challenge, particularly in the early stages of development. Regulations that require transparency, due diligence and the substantiation of environmental and social claims are often an obstacle for companies. Data uncertainties, a lack of information in the supply chain or effects in the value chain that cannot be influenced inhibit the spirit of innovation. Can regulation be incorporated into research and development? Where are the current weak points and what conclusions can be drawn from projects that in turn influence the further development of regulation and help define new political measures?

Through case studies dealing with emerging development, technologies and markets, this presentation highlights how sustainability assessments can guide industries through these challenges, enabling informed decision-making that balances environmental, economic, and social factors by simultaneously fostering sustainable innovation.

This work derives from several past and ongoing R&D projects, in particular ECO2LIB (H2020, 875514), ZDZW (HEU, 101057404), AID4GREENEST (HEU, 101091912) and PhotonQBoost (HEU, 101177922).

One Person's Trash is Another's Treasure: Assessing the Life Cycle Sustainability of Bio-Based Innovations in Brewery By-Product Valorisation

Dimitri Chryssolouris[1], Franziska Stoessel[1], Alfredo Rodrigo[2], Matthias Stucki[1]

[1]Zurich University of Applied Sciences (ZHAW), Switzerland; [2]AINIA, Centro Tecnológico (AINIA), Spain

Agricultural residues and by-products are often not valorised and still considered waste rather than a valuable resources. Recognising their potential enables the adoption of a biorefinery approach to produce high value-added products. Beer production holds significant potential for utilising residues and by-products. In Europe alone, 346 million hectolitres of beer were produced in 2023, generating 20 kilograms of by-products and waste streams per hectolitres, including brewer's spent grains (BSG), spent yeast, wa-

stewater, and CO2 from fermentation.

The Horizon Europe project CHEERS leverage these underutilised residues and by-products of beer production to create five competitive and innovative bio-based products, namely insect protein powder (1), single-cell protein (2), volatile fatty acids (3), chlorine (4), and ectoine (5). Insect protein is produced by feeding brewer's spent grains to mealworms, while the other four products are derived through microbiological processes. Carbon dioxide from beer fermentation serves as an input for these processes. Together with methane from the anaerobic digestion of wastewater, it is used to produce single-cell protein (2) and volatile fatty acids (3) as ingredients for pet food, chlorine (4) for disinfectants, and ectoine (5) for cosmetic products.

Foreground data on the life cycle of these bio-based refineries was collected to conduct a cradle-to-grave life cycle sustainability assessment (LCSA). The results were compared with reference products made from fossil-based materials, enabling a discussion of synergies and trade-offs. The project seeks to develop a holistic understanding of the environmental, economic, and social impacts associated with the evaluated products.

An initial screening LCA revealed that high energy consumption is the primary driver of environmental impacts in bio-based production at the pilot scale. These findings were further refined through validation using up-scaling (ex-ante) scenarios. At the LCM 2025 conference, the environmental, economic, and social impacts of this bio-based economy will be presented, alongside various ex-ante scenarios.

Life Cycle Assessment of a novel technology based on combined gasification and combustion of low value biomass for industrial applications. Preliminary assessment.

Khaled Mohamed Ahmed Osman, Blanca Corona, Ric Hoefnagels, Martin Junginger

Utrecht University, Netherlands

The Clean Bioenergy for Industry (CBE4I) project presents a groundbreaking solution to decarbonize industrial heat production through an innovative biomass-to-heat technology. Developed under European Commission funding, CBE4I combines advanced gasification and combustion processes to deliver highly efficient, near-zero-emission, and almost waste-free heat for industrial applications. By utilizing low-value biomass residues with no alternative use, the system achieves remarkable efficiency (up to 120%) and integrates cutting-edge features such as a fuel-flexible gasifier, novel NOx reduction technology.

This study conducts a cradle-to-grave Life Cycle Assessment (LCA) to evaluate the environmental sustainability of the CBE4I technology. Adopting the ISO-compliant Environmental Footprint 3.1 methodology and leveraging primary data from industry partners, the assessment provides precise insights into environmental impacts across resource inputs, system operations, and waste management. The analysis bridges critical gaps in existing LCA studies by addressing previously unexplored processes and relying on up-to-date, optimized industrial data.

Preliminary results reveal substantial reductions in greenhouse gas emissions and biomass consumption, alongside enhanced energy recovery, circular economy and environmental benefits through replacing fossil based sources. Sensitivity analyses further validate the system's performance across diverse scenarios, ensuring reliability and robustness.

This research underscores the transformative potential of CBE4I in advancing sustainable energy systems and supports decision-making for cleaner industrial processes. It not only identifies environmental hotspots to guide technology optimization but also establishes a replicable model for scaling renewable industrial heat technologies. By aligning with the European Green Deal's decarbonization targets, CBE4I demonstrates how innovation in life cycle management can drive impactful solutions for a low-carbon energy transition.

Beyond the Surface: How Durability Drives Lower Carbon Footprints in Coating Technologies

Ramin Ghamkhar, Jessica Slomka

Sherwin-Williams, United States of America

In the pursuit of sustainable materials, the role of durability is often undervalued in environmental assessments. This presentation explores the direct relationship between durability/quality and lower carbon footprints in coating product technologies, drawing on performance and life cycle data. As one of the few in the industry to incorporate performance testing into Life Cycle Assessments (LCAs) and Environmental Product Declarations (EPDs), we demonstrate how accounting for durability shifts the environmental trade-offs, often resulting in significantly lower impacts over the product's life span. By comparing scenarios with and without performance data, we reveal how the exclusion of durability can lead to misleading sustainability conclusions. This case study highlights the importance of integrating real-world performance into environmental assessments to more accurately reflect the true sustainability of high performing products.

A Two-Tier Social Life Cycle Assessment Framework for Emerging Hydrogen Technologies

Alessandra Zamagni[1], Lucia Mancini[2], Umberto Eynard[3], Alessandro Arrigoni[4]

Organization(s): [1] Ecoinnovazione, Italy; [2]Trasys International, Network Research Belgium S.A. (NRB), Herstal, Belgium; [3]European Commission Joint Research Centre, Ispra; [4]European Commission Joint Research Centre, Petten

As hydrogen becomes increasingly crucial in EU decarbonization strategies, understanding its social implications is essential for ensuring a just and sustainable energy transition. Research on the societal effects of the hydrogen transition is in its infancy, and criteria to support a social assessment of hydrogen technologies are not fully developed yet. Moreover, current Social Life Cycle Assessment (S-LCA) methodology faces significant limitations when applied to emerging hydrogen technologies, particularly in addressing macro-level objectives and adapting to the different Technology Readiness Levels (TRLs).

This contribution presents a proposal of a conceptual framework for assessing social impacts and risks across hydrogen technology value chains, by integrating sustainability science principles with life cycle thinking and S-LCA methodology in particular. Risk and equity represent the framework's ontological foundations, which drive the identification of material social impacts organized into two categories: overarching system-level impacts (justice and resilience) and technology-specific impacts (working conditions, employment creation, innovation potential, and quality of life). The framework employs a Driver-Pressure-State-Impact-Response (DPSIR) approach to structure social indicators, addressing both global supply chain risks and local community effects.

Further development is needed for making the framework fully operational. Some indicators require additional attention, particularly for measuring affordability and landscape quality impacts. In this regard, the operationalisation of the framework will benefit from the outcomes of an ongoing case study, that is expected to provide useful information for addressing gaps in indicator measurement. In addition, the development of sector-specific indicator sets for different hydrogen applications (transport, industry, energy storage) could enhance its practical applicability.

Sustainability assessment of implementing nanowire solar cells in space

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The growing demand for efficient and reliable energy systems in space exploration and satellite operations is fueled by the increasing complexity and extended duration of missions. Photovoltaics (PV) are pivotal in fulfilling these energy demands, with advancements in high-efficiency solar cells offering transformative potential for space applications. Among their primary benefits are a drastic reduction in the use of critical raw materials and the incorporation of wireless power transmission, which opens the door to novel in-space applications.

ZEUS seeks to develop cutting-edge PV technologies, developing nanowire tandem-junction solar cells for space applications. By advancing nanowire PV to achieve efficiencies exceeding 35%, the initiative aims to create ultra-flexible solar cells that can be seamlessly integrated with wireless power transmission systems using nanowire technology. The nanowire-based tandem junction photovoltaics are being optimized to reach target efficiencies of up to 47%, positioning them as a robust solution for the demanding conditions of space. The development strategy relies on material systems such as GaAs/GaInP and InAsP/InP tandem junction nanowires, which provides a strong framework for achieving superior energy conversion efficiency.

For sustainability assessment, Life Cycle Assessment (LCA) is widely regarded as the best option due to its comprehensive, standardized, and systematic approach to evaluating environmental impacts. LCA is a critical tool for ensuring the environmental sustainability of advanced nanowire solar cell technologies developed for space applications. By systematically evaluating the environmental impacts across the entire lifecycle - from raw material extraction and manufacturing to deployment and end-of-life management - LCA provides insights into the resource efficiency, energy consumption, and carbon footprint of technology. This project leverages LCA to identify environmental “hotspots,” optimize material usage, and assess the recyclability of critical components, such as the III-V material based tandem junction nanowires.

Session 3.18: Methodologies and Tools for Sustainable Agriculture and Food Value Chains Part II

Time: Friday, 12/Sept/2025: 2:30pm - 4:00pm
Session Chair: Andrea Di Maria, University of Liege, Belgium
Session Chair: Roland Meyer, INaB - RWTH Aachen, Germany

Durum wheat production in Sicily, Italy: Evaluating the environmental impacts of conventional vs. organic farming systems

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Wheat production is a cornerstone of global food security, essential for sustaining populations worldwide, and it covers approximately 219 million hectares globally. Its production requires substantial material and energy inputs, including fertilisers, pesticides and fuel. These inputs contribute to environmental degradation and biodiversity loss, raising concern about the sustainability of agricultural practices. In the context of global climate change and environmental threats, mitigating the impact of agricultural activities is urgent. The aim of this study was to evaluate and compare the environmental impacts of conventional and organic wheat grain production systems in Sicily using the Life Cycle Assessment (LCA) methodology. Surveys were conducted during the 2021/2022 season, collecting data from 14 conventional and 7 organic farms. A "cradle to gate" approach was applied, considering all the wheat cultivation processes. The functional unit was yield-scaled (per ton of wheat grain production). Ecoinvent v.3.0 was used as database for secondary data, when the necessary primary information was unavailable. The analysis was carried out using SimaPro 9.5.0.1, employing the CML-IA baseline impact assessment method. The results indicated that marine aquatic ecotoxicity was the most affected impact category, ranging from 1.30E+05 to 1.05E+06 kg 1,4-B eq. Conventional system had a higher impact, due to pesticides and fertilisers production and transport. Only eutrophication (with values ranging from 3.34E-01 to 5.54E+00 kg PO4 eq.) was primarily influenced by fertilization practices. Organic system, with fewer inputs, had impact mainly associated with fuel production and use. No significant differences were observed between self-produced and locally sourced seeds. These results will provide valuable insight for developing a strategy to reduce the environmental impact of the wheat production system.

Funding: This abstract is part of the project NODES which has received funding from the MUR - M4C2 1.5 of PNRR funded by the European Union - NextGenerationEU (Grant agreement no. ECS00000036).

Enhancing Sustainability in the Food Value Chain: A Three-Dimensional Methodological Assessment of Innovative Food Product Design

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Sustainable food product design is essential to minimizing global impacts across the food value chain. This study focuses on developing innovative food products and evaluating their sustainability through environmental, economic, and social dimensions. Using Life Cycle Assessment (LCA), the environmental impacts are assessed to identify and improve hotspots. Economic sustainability method integrates global economic factors with Life Cycle Costing (LCC), bridging gaps in economic assessments. For social impact methodology, the Social Life Cycle Assessment (S-LCA) is enhanced by combining product-specific factors with

global social issues sourced from the Social Hotspots Database (SHDB), resulting in 21 social criteria.

This research employs a holistic approach to evaluate novel food products enriched with plant proteins and bioactive compounds, processed through advanced drying technologies. The impacts are assessed on a functional unit of single packaged samples across 32 criteria from cradle to market. An expert panel of eleven applies the Analytic Hierarchy Process (AHP) to assign weights to the criteria, enhancing the accuracy of performance evaluation. Multi-criteria decision analysis techniques, TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) and SAW (Simple Additive Weighting), are used to integrate the three sustainability dimensions, refining the overall sustainability score to enable effective benchmarking.

Results demonstrate that including product-specific criteria, such as sensory quality and nutritional content, can influence sustainability rankings within the food value chain. Among the products evaluated, those formulated with pea protein and processed using MW vacuum drying achieved the highest sustainability scores. The findings reveal that the region where pea protein is sourced entails certain social risks, while tray drying methods, though less cost-effective than MW vacuum or conventional dryers, offer high economic returns and labor productivity.This study will provide a practical roadmap for stakeholders across the food value chain, enabling sustainability assessments at the early stages of product design.

Assessing Efficiency and Environmental Sustainability in Northern Spain's Fishing Fleets: An Integrated LCA+DEA Approach with the WEF Nexus

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The fishing sector constitutes an important source within the economy of northern Spain, primarily due to the region's expansive coastline and numerous fishing ports. However, fishing operations generate various direct environmental impacts, alongside indirect and off-site effects. In response, numerous studies have examined the use of Life Cycle Assessment (LCA) and Data Envelopment Analysis (DEA) in fishing systems. However, these studies generally rely on environmental indicators that focus on isolated issues, limiting progress toward comprehensive resource management. Therefore, this study introduces the water–energy–food (WEF) nexus as an integrated approach that assesses the interactions and trade-offs between water usage, energy consumption, and carbon emissions.

In this context, the main objective of this research is to assess the operational efficiency and environmental impact of Cantabrian fishing fleets. To this end, the combined use of LCA and DEA, along with the WEF nexus, was applied to the Cantabrian purse seine fleet to understand the eco-efficiency and potential environmental benefits of operating at higher levels of efficiency within this fleet.

The fleet's average efficiency exceeded 60%, with the less efficient units showing significant potential to reduce their environmental impacts—by as much as 65%—if they operate according to the projected efficiency targets. This emphasizes the importance of identifying and addressing areas for improvement in order to maximize efficiency and minimize environmental impact across the entire fleet. Furthermore, the findings demonstrate a strong dependence of environmental impacts on one of the operational inputs (i.e., fuel consumption). These results underscore the need to adopt holistic approaches that integrate technical, economic, and social factors to achieve a sustainable balance in fisheries systems. In this context, the five-step LCA+DEA method, when combined with the WEF nexus, proves to be an effective tool for evaluating both operational and environmental goals.

Balancing Sustainability and Stability: What Matters More for Enhancing Sustainability - Short or Long Food Supply Chains and Production Methods?

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There is growing interest in reconnecting agriculture and food consumption through Short Food Supply Chains (SFSCs), particularly those incorporating organic production. While SFSCs promote alternative farming practices and attract organic producers, their environmental performance and capacity for stable supply remain underexplored. Challenges such as limited product variety, reduced volumes, and lower yields in organic farming compared to conventional methods complicate their sustainability. Moreover, existing research often emphasizes single environmental metrics, like carbon footprint, without considering the diverse regional production and commercialization patterns.

This study evaluates the environmental and economic sustainability of various food supply chain patterns using a lifecycle assessment approach, analyzing eight categories, including greenhouse gas (GHG) emissions and water resource consumption. The analysis focuses on fresh, unprocessed tomatoes purchased in an urban area and examines the impacts of production methods and intermediary activities in Japan's food system. By modeling the national supply chain, the study identifies strategies to reduce environmental impacts from production practices and midstream supply chain activities.

The findings reveal that GHG emissions and water consumption vary based on the production area's distance to the consumption point and the cultivation method (conventional or pesticide-free). Pesticide-free tomatoes exhibited lower GHG emissions per unit area but higher emissions per product unit due to reduced yields and less efficient transportation. Intermediaries played a crucial role: wholesale markets, as midstream actors, reduced environmental impacts for distant production areas, while direct sales, a key feature of SFSCs, performed better for areas closer to consumption.

These results highlight the importance of tailoring production methods and intermediary activities to specific contexts. The study concludes with recommendations for targeted interventions involving intermediaries to enhance environmental performance and support a stable, sustainable food supply chain.

Comparing Environmental Assessment Methods: Olive Oil Producers in Central Italy study case

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Italy is the second European producer of olive oil, with about 1 million hectares dedicated to its production, defining the landscape of several areas across the country. The tradition and cultural value of this sector raises concerns about improving production allied to reduced environmental impacts. This study investigates the environmental profile of two small-sized olive oil producers in Italy, applying carbon footprint (CF) and Product Environmental Footprint (PEF) methodologies. Environmental assessments were conducted before and after the implementation of compensatory measures by the olive oil producers, such as the use of olive leaves and horse manure as organic fertilizer/amendment. A cradle-to-gate approach was employed, with the functional unit defined as 1 litre of olive oil packaged in glass bottles. Results demonstrate that the first farm achieved a reduction in environmental impact of 36.2% for CF (expressed as kgCO2eq/l) and 35.9% for PEF (expressed as kgCO2eq/l), following the compensatory practices. Analysis revealed that environmental impacts are associated with upstream processes, notably olive production and packaging materials. Specifically, nitrogen emissions from pruning residues scattered on the soil predominantly contribute to impacts during olive cultivation, while glass bottle production significantly impacts the packaging stage. During oil extraction, energy consumption represents the main source of environmental impact. Conversely, the second farm experienced an increase in environmental impact, with CF rising by 45.6% and PEF

by 38.0%. Similarly, the upstream stage, particularly agricultural operations, accounts for most of these impacts. Future research should cover social and economic perspectives of sustainable practice in the sector mainly constituted by small producers to identify differences among agri-food management practices and provide more consistent recommendations for the production from cradle to gate.

Developing a Framework for Sustainability Scoring of Food Products

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Food production practices vary widely due to regional differences in resources, market dynamics, and politics, leading to significant environmental and social impacts. Addressing these challenges demands a collaborative approach that engages stakeholders across the food system. The Norwegian research project, NewTools, aims to create a robust framework for evaluating the environmental and social sustainability of food products to enable a shift toward more sustainable production practices by facilitating consumer choices that prioritise environmental and social responsibility.

To define the framework, the Product Environmental Footprint (PEF) methodology was used as a starting point for inclusion of environmental categories and a stakeholder survey was integrated with a hotspot analysis to identify the most relevant social categories to be included. Indicators for each category were then developed based on core principles from the UNEP guidelines for Providing Product Sustainability Information: reliability, relevance, clarity, transparency, and accessibility(UNEP, 2017).

The assessment data were evaluated using a five-level scale, with thresholds determined by percentile-based data distribution. A single score was developed for environmental and social sustainability, respectively. For environmental sustainability, the Environmental Footprint weighting system (Sala et al., 2018) was adapted to cover all relevant indicators. In contrast, the social sustainability score was aggregated using a tailored weighting system incorporating three principles: (1) distance to target, (2) policy relevance, and (3) expert panel evaluation. The impact of these weighting methodologies was analysed to assess their effect on scoring outcomes.

The findings emphasize the importance of integrating stakeholder insights, global guidelines, and applying robust weighting systems that reflects the relative importance of diverse environmental and social sustainability criteria.

Integrating Multi-Criteria Decision-Making with Multi-Objective Optimization for Sustainable Diet Design

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We propose a method for enhancing diet sustainability by integrating multi-criteria decision-making (MCDM) with multi-objective optimization (MOO). A sustainable diet must reconcile cultural acceptability, nutritional adequacy, and environmental sustainability. However, individual food groups may score high on one criterion but low on others, necessitating the use of multiple indicators to capture the full spectrum of sustainability. This multi-indicator approach increases the complexity of both the optimization process and the interpretation of its outcomes. To manage this complexity, we employed the SURE method as an MCDM tool prior to applying MOO, thereby reducing the number of objectives. The SURE score aggregates multiple environmental indicators, reflecting their conflicting nature while simplifying the optimization task. We applied this approach to optimize the Estonian diet. Food consumption data for Estonia were classified into 14 groups, and environmental footprint data with associated uncertainty ranges were compiled for analysis. A bi-objective optimization model was developed to concurrently minimize five aggregated envi-

ronmental footprints and deviations from the baseline diet, while ensuring nutritional requirements were met. For comparison, a conventional multi-objective optimization framework was also implemented. Both approaches effectively reduced environmental impacts, but the bi-objective model provided a more accessible decision-making process, offering visual outputs and allowing for easier adjustment of objective weights based on stakeholder preferences. This methodology supports the development of sustainable diets by clarifying complex trade-offs and offering a robust framework for evidence-based decision-making.

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Reducing the carbon footprint of food products: a methodology for sustainable value chain practices

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The food and agricultural sectors are significant contributors to global greenhouse gas emissions, presenting major challenges to sustainability and efforts to combat global warming. Reducing their carbon footprint is essential to address environmental concerns and promote a more sustainable future.

The developed methodology aims to lower the carbon footprint linked to the average basket size associated with Portuguese consumption patterns. This approach focuses on minimizing environmental impacts throughout the value chain of various products by incorporating best practices into their production processes.

Through Life Cycle Assessments (LCAs) with cradle-to-gate boundaries, key points in the production processes that significantly contribute to greenhouse gas emissions can be identified. By comparing similar products from different suppliers, this methodology highlights which practices are more sustainable at specific production stages. The insights gained from these assessments are used to develop a comprehensive guide for suppliers, outlining opportunities for improvement and offering actionable recommendations to reduce carbon emissions.

This methodology differs from traditional approaches that typically prioritize the best-performing suppliers. Instead, it fosters inclusivity by keeping all suppliers in the network and encouraging collective improvements in production processes. This collaborative strategy ensures that the entire supply chain can benefit from reduced environmental impacts while not compromising diversity and competition.

This approach outlines a practical and scalable way to reduce the carbon footprint of food products, accelerating the transition to a more sustainable supply chain. By tackling emissions at their source and providing suppliers with insights and support, this methodology not only reduces the environmental impact of the average basket size but also promotes a culture of collaboration and shared responsibility. It establishes a precedent for how industries can work together to achieve significant sustainability transformations.