ABSTRACT BOOK

SETAC Europe 25th LCA Symposium

12–14 October 2022 | Virtual Event

"The Role of LCA in Raw Material Sustainability, Circularity and Criticality"

Abstract Book

SETAC Europe 25th LCA Symposium

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This book compiles the abstracts from 25th Life Cycle Assessment Symposium of the Society of Environmental Toxicology and Chemistry – Europe (SETAC Europe), conducted from 12–14 October 2022 online. The abstracts are reproduced as submitted by the author and accepted by the scientific Committee.

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1 Energy Technologies and Energy System

1.01 Comparative Environmental Life Cycle Assessment of a Stilted and Vertical Bifacial Agri-Photovoltaic System

***Theresa Krexner**, Alexander Bauer, Francisco Medel, Andreas Gronauer and Iris Kral, Institute of Agricultural Engineering, University of Natural Resources and Life Sciences, Vienna, Austria*

Agri-Photovoltaic (APV), the double use of agricultural land for food/feed and electricity production via photovoltaic (PV)-modules, has been a popular topic of research in recent years. So far, no holistic assessment of environmental impacts has been done. Hence, this study aims to compare a stilted (S-) with a vertical bifacial (VB-) APV system from cradle-to-gate with the life cycle assessment method using system expansion. Further, the scenarios of an unmodified agricultural production (Agri-only) and a total substitution of the latter by PV-modules (PV-only) are assessed. For a fair comparison the same outputs must be produced in every scenario. Hence in the Agri-only scenario an additional production chain for electricity (Austrian production or green electricity) is added; while agricultural production is added in the PV-only and S-APV scenario. As functional unit (FU) a sum of electricity and agricultural goods is used: 1 kWh electricity+50.29 g sugar beet+1.92 g soybean+7.85 g winter wheat. The impact categories global warming potential (GWP), human toxicity (HCT), terrestrial ecotoxicity and acidification (TAP), freshwater and marine eutrophication (MEP), fine particulate matter formation, mineral and fossil resource scarcity are assessed. Overall, the PV part is related to higher (up to 99.37 %) environmental impacts than the agricultural part in all studied impact categories in all scenarios, except for MEP, in which the nitrate emissions are accountable for the higher share. Compared to the Agri only scenario with Austrian produced electricity the VB-APV system can reduce environmental impacts by 15-81%, the S-APV system for 3-70% except for HCT and TAP, where the scenario has the highest contributions due to the high steel demand for the mounting structure and the PV-panel production. A hotspot in both APV-scenarios is the PV-module production in China, due to the high demand and impact of electricity, in the S-APV scenario further the steel mounting structure. Results show a GWP of 49 g CO_2 eq. per FU for VB-APV and 73 for S-APV, respectively, while being slightly higher for the PV-only scenario (80 g CO_2 eq. per FU); for the Agri-only scenario it depends which electricity mix is used for system expansion (26 and 176 g CO_2 eq. per FU for the green and Austrian mix, respectively). Overall, it is shown that APV-systems can reduce environmental impacts compared to the Agri-only scenario with Austrian produced electricity.

1.02 Life Cycle Assessment of Salinity Gradient Energy Recovery by Reverse Electrodialysis in Coastal Municipal Wastewater Treatment Plants

*Liselotte Schebek, Laura Göllner-Völker and **Diego Mauricio Olaya Pinto**, Technical University of Darmstadt, Germany*

Salinity gradient energy is a renewable energy source that can be obtained from the mixture of two solutions with different salinity. Reverse electrodialysis (RED) is one technology capable of harvesting this type of energy. As with other renewable energy technologies, the environmental burdens of these systems have to be assessed to determine its ideal context of application, and to support decision-making. Although previous authors have used life cycle assessment (LCA) to quantify the potential environmental impacts of RED systems, this is the first study in the context of a coastal municipal wastewater treatment plant (CMWWTP). We conducted a consequential LCA with a functional unit of 1 kWh of net electricity production, allowing comparison with similar on-site renewable energy technologies, such as photovoltaics. Two scenarios were assessed: the installation and operation of a real prototype of this technology in a CMWWTP installed in Spain, consisting of two RED modules, and the upscaling of this prototype into a system of 100 RED modules. The results of the LCA present an inferior environmental performance of RED in CMWWTPs when compared to other sources of electric power. The result values are closely related to the low energy efficiency of the system and the high amount of supplementary equipment required for its operation, such as pumps and other infrastructure. Further research is required to increase the net amount of electricity produced and to employ more durable and sustainable materials for the system infrastructure.

1.03 Exploring the Material Criticality of Two Hydrogen-related Products Under Different Indicators

***Felipe Campos Carriedo**[1], Gonzalo Puig-Samper[1], Álvaro García Díaz[2], Eleonora Bargiacchi[1], Diego Iribarren[1] and Javier Dufour[1], (1)Systems Analysis Unit, IMDEA Energy, Spain, (2)Rey Juan Carlos University, Spain*

The fuel cells and hydrogen (FCH) sector is expected to play a key role in the energy transition. For instance, gigawatts of water electrolysis capacity are expected to be installed in Europe by 2030, and millions of vehicles could be powered by hydrogen in 2050. It is crucial to ensure that the deployment of hydrogen systems is conducted without burden shifting across sustainability dimensions. In particular, the issue of raw material criticality has gained attention in recent years because of the growing demand for minerals associated with clean energy technologies. This work quantitatively explores the criticality of two FCH products through different indicators. The two products under study are a 5 kW solid oxide electrolysis cell (SOEC) stack for hydrogen production, and a 48 kW proton exchange membrane fuel cell (PEMFC) stack for hydrogen use. The applied criticality indicators were based on a recent review on criticality assessment methods, as well as on current trends specific to FCH products. Accordingly, three approaches aligned with the European Commission's framework (supply risk divided by global or European production, and the EcoReport criticality indicator) and the GeoPolRisk (GPR) midpoint indicator were implemented. Regarding the 48 kW PEMFC stack, platinum arose as the main criticality hotspot under all the approaches considered in the study. Only in the case of the GPR midpoint indicator, other materials (copper and steel) also showed relevant contributions. On the other hand, concerning the 5 kW SOEC stack, the identification of the most relevant materials was found to be highly dependent on the selected assessment approach. Yttrium was the only material involving a substantial contribution under each of the indicators. Overall, further research to quantify the relevance of the sub-indicators involved in the calculation of the considered indicators is needed to gain an insight into the implications of prioritising a specific approach within the FCH sector.

This work was carried out in the context of eGHOST. This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) under Grant Agreement No 101007166. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation programme, Hydrogen Europe and Hydrogen Europe Research.

1.04 Environmental Performance of a Hybrid Solar-hydrogen Cogeneration System for Residential Applications

Gabriel Naumann, *Natascha Steegmann, Elke Schropp and Matthias Gaderer, Professorship of Regenerative Energy Systems, Technical University of Munich, Germany*

Due to the strong dependence on fossil fuels, emissions from heating systems account for a significant portion of anthropogenic environmental pollution in Germany. Therefore, it is crucial to transform the heat supply towards renewable energy. Heat pumps using renewable energy were identified as a key technology for the future heat supply. However, most of the heat is needed in the winter months, when renewable electricity generation is at its lowest. As a result, there is the risk that heat pumps will be powered by fossil-generated electricity. One approach to using solar electricity generated in summer in the heating sector is hybrid solar-hydrogen systems consisting of photovoltaic modules for electricity production, a battery as short-term storage, an electrolyzer system as long-term storage, a fuel cell, and a heat pump. Such systems store surplus solar electricity from the summer in the form of hydrogen for the winter. During the winter, fuel cells use hydrogen to supply the building with electricity to run the heat pump. Waste heat produced by both the electrolyzer and the fuel cell can be transferred to a hot water tank, resulting in partial coverage of the heat demand.

This study aims to determine the environmental impact of the hybrid solar-hydrogen cogeneration system and compare the results to a conventional system with a PV-assisted heat pump. For this purpose, the systems are integrated in a new single-family house located in Germany, which serves as the reference building. The environmental impacts are analyzed using the life cycle methodology, focusing on the manufacturing and operation phases. In the operation phase, the integration of the hydrogen system leads to a reduced grid electricity consumption and thus lowers the caused emissions. However, in the manufacturing phase the environmental impacts increase due to a higher material demand of the hybrid system based on PV and hydrogen and the need of critical raw materials. Therefore, this study analyzes the manufacturing phase and offsets it against the reductions in the operation phase to ensure a holistic result and avoid burden shifting between phases.

1.05 Future Environmental Performance of an Emerging Hydrogen Production Technology Using Anion Exchange Membranes

Elke Schropp[1], *Gabriel Naumann*[1], *Bernhard Steubing*[2] *and Matthias Gaderer*[1], *(1)Professorship of Regenerative Energy Systems, Technical University of Munich, Germany, (2)Institute of Environmental Sciences (CML), Leiden University, Netherlands*

Hydrogen production by water electrolysis, in which water is split into hydrogen and oxygen using electricity, is considered a key technology for the energy transition towards renewable and climate-friendly technologies. The already mature water electrolysis technologies such as alkaline electrolysis (AEL) or proton exchange membrane electrolysis (PEMEL) can provide hydrogen with relatively low environmental impacts if they use renewable energy. However, there are some environmental issues like the use of rare platinum group metals in PEMEL. When thinking of large-scale megawatt plants, these issues can add up to severe problems, so we should strive to minimize the environmental impacts of hydrogen production.

This study aims to analyze the environmental performance of an emerging water electrolysis technology that promises efficient and low-cost production of hydrogen without the use of noble and potentially critical materials: the anion exchange membrane electrolysis (AEMEL). To analyze the environmental performance of an emerging technology, which is still under development, the prospective life cycle assessment (pLCA) approach is suitable. This approach is based on the integration of different scenarios representing possible future developments of the technology. Thus, the pLCA results show the environmental performance of the AEMEL technology for different development paths, ranging from best-case development to more conservative development. Finally, these results can be compared to incumbent technologies such as the AEL and PEMEL technologies.

Due to the use of non-critical materials and high achievable efficiency, AEMEL technology has the potential to reduce environmental impacts compared to incumbent technologies. Nevertheless, new materials are required, for example for the membrane, which have not yet been analyzed and could have impacts that offset the aforementioned advantages.

1 Energy Technologies and Energy System (Poster)

1.P.01 Analysis of Changes in Household Air Conditioning Energy Demand by COVID-19 Using Big Data

Genta Sugiyama[1], *Tomonori Honda*[2] *and Norihiro Itsubo*[1], *(1) Tokyo City University, Japan, (2)Global Zero Emission Research Center, National Institute of Advanced Industrial Science and Technology, Japan*

The COVID-19 pandemic has changed energy demand. Restrictions on people's activities have increased telecommuting efforts and time spent indoors, contributing to increased energy consumption in the residential sector. Among other things, the time spent using air conditioning increased by up to 60% compared to pre-pandemic levels, suggesting that this trend may continue over the long term due to continued telecommuting and other factors. In addition, demand for air conditioners is expected to increase further, with three-quarters of the world's population owning air conditioners by 2050 as a result of rising temperatures and economic growth, which is projected to triple global energy consumption. The use of air conditioners and other air conditioning equipment accounts for about one-fifth of the total electricity used in buildings, or 10% of global electricity consumption, and this trend is expected to further expand in countries with significant economic and population growth. In the LCA case study of residential air conditioners, 90% of the environmental impact is accounted for by the stage of use, indicating that the results vary greatly depending on local climate, product function, operating conditions, and other factors. However, in most cases, the use stage is based on values obtained from questionnaire surveys, and analysis that reflects the actual conditions of use has not been conducted.

In this study, hourly data for 70,000 residential air conditioners were used to elucidate the actual status of air conditioning use, and changes in energy consumption were analyzed for 2019 before the pandemic and 2020 during the pandemic. The analysis revealed that the average annual energy consumption associated with household air conditioning use in Japan as a whole is 570 kwh, which is equivalent to 13% of Japan's total household electricity consumption. It was suggested that the usage time and energy consumption assumed by the Japanese Industrial Standards (JIS) may be overestimated by about 50% compared to the actual usage. In addition, due to the increase in home time caused by the pandemic, annual hours of use and electricity consumption in 2020 are expected to increase by 20% and about 23%, respectively, compared to 2019, which is equivalent to 16% of total household electricity consumption in Japan. In the future, trends in air conditioning use by region and cooling capacity will be identified and analyzed by attribute.

1.P.02 Exergy Based Life Cycle Assessment of Power-to-X and Carbon Capture and Utilization Applications

Janis Gerhardt-Mörsdorf *and Christine Minke, Institute of Mineral and Waste Processing, Recycling and Circular Economy Systems, Clausthal University of Technology, Germany*

The extraction of resources from ecosystems for the current take-make-dispose economic system can result in their depletion. On the other hand, production processes generate wastes and emissions to the ecosystem. These facts severely endanger the prospects for future generations. Life Cycle Assessment (LCA) is a standardized methodology for assessing the potential environmental impacts of products and processes or services throughout their lifetime, identifying hot spots and revealing impact reductions by means of material and energy balances. However, a material and energy balance, per se, is not sufficient to be a good environmental indicator. It does provide a measure of the quantitative throughput of a process, a sector or the society, but it cannot measure the intrinsic quality of that throughput. Exergy however, is a measure for the quantity and quality of both energy and material streams on a single scale. There is a direct relation between exergy and the environmental threat of depletion of natural resources. If a society consumes its exergy sources at a faster rate than they are renewed, it will not be sustainable. Thus, increasing the exergy efficiency of processes, leads to the reduction of resource consumption and environmental impacts. Several hybrid approaches for LCA and exergy analysis have been proposed and are introduced. Exergy based life cycle methodologies typically extend the scope of the classic exergy analysis to the complete supply chain of a process. The Power-to-X (PtX) and Carbon Capture and Utilization (CCU) concepts are part of the circular economy approach that support closing the carbon cycle. In the PtX concept, electricity from renewables is converted to other energy vectors, such as chemicals or fuels. Several LCA studies on PtX and CCU systems exist in literature and have been reviewed in detail. However, these studies solely focus on conventional Life Cycle Impact Assessment (LCIA) impact categories, disregarding thermodynamic irreversibilities of the process life cycles. This study aims at reviewing the literature for life cycle exergy analysis of PtX and CCU applications to determine the current state of the research and identify which exergy based LCA methods are applied most commonly. Furthermore, it is analyzed whether the correlation between exergy based impact categories and traditional ones can be confirmed for PtX and CCU applications.

1.P.03 LCA Meta-analysis on Hydrogen and Ammonia Production

Runya Liu *and Norihiro Itsubo, Department of environmental information, Tokyo city university, Japan*

Hydrogen is a significant strategic energy source that will not only play an important part in future energy security but will also contribute to carbon neutralization. We conducted a meta-analysis of hydrogen in LCA research from 2017 to 2022 in this paper. So far, over 20 publications have been analyzed, with over 120 samples included in our meta-analysis. We focused on assessing the carbon footprints, research limitations, and research interests of various kinds of hydrogen generation. The study examined several aspects of hydrogen energy, with a focus on research from the cradle-to-gate phase. The environmental impact categories may include global warming, acidification, and other LCIA categories. According to recent research, the various types of hydrogen, transportation, manufacturing processes, etc, have large concentrations but little analysis. Fill out the research blanks to have a comprehensive understanding of those prospective renewable energy sources. This study intends to comprehend the state-of-the-art research status quo on the environmental effect of hydrogen energy, with the goal of providing rigorous scientific proof and advice to policymakers and stakeholders when constructing future energy architectures.

1.P.04 Unified Approach of the Environmental and Economic Assessment for Electric Vehicles Lithium-ion Batteries on a Circular Economy Perspective

Gabriela Benveniste*, Victor Ferreira, Tomás Montes and Cristina Corchero, Catalonia Institute for Energy Research-IREC, Spain*

MARBEL is an EU-funded project that aims the implementation of the circular economy (CE) principles in the batteries packs (BP) made by design and to support the automotive sector for the widespread penetration of electric vehicles (EV). In order to provide a quantitative comparison of the environmental and economic benefits of MARBEL's developed technology, the best procedure is through a unified approach by using two methodologies to explore possible "trade-offs" and to make sustainable design and analysis decisions. The unified approach follows the Life Cycle Assessment (LCA) and Life Cycle Costing Assessment (LCCA) methodologies. Firstly, a cradle-to-gate scope is conducted. In this scope, the entire life cycle of the production of the battery is included, segregated in two different life cycle stages, starting at component production which includes raw material and energy extraction, and then followed by the battery manufacture, including all intermediate steps until obtaining the battery and its use in the vehicle. The second scope (cradle-to-grave, F.U: 1 kWh) holds the battery production, its use on an electric vehicle and the end-of-life stages of the battery, including applications in a second life of battery. Using batteries after their first life in an EV is a great opportunity to reduce the environmental impact, reduce the use of raw materials and increase the economic benefits before recycling the battery. The use phase includes the impacts mainly caused by the amount of electricity lost during the recharging phase over the whole life of the battery, whereas the end-of-life stage includes the impacts associated with the energy needed to disassemble the battery and prepare it for a second life, which will lengthen the useful life of the battery components. The system boundaries are aligned with the goal of the study and includes the two approaches mentioned above. As a general remark, applying the LCA and LCC tools on both approaches, designers can insight a fuller answer and increase robustness and understanding about the environmental and economic performance through life cycle stages to gain potential knowledge about different aspects and overall, a better and more complete picture.

1.P.05 Life Cycle Assessment and Circularity Indicators to Design Future Circular and Sustainable Electric Outboards: Results from Workshops with Industrial Experts

Michael Saidani[1]*, John Bayless*[2] *and Harrison Kim*[1]*, (1)University of Illinois, United States of America, (2)Brunswick, United States of America*

Electrification is a key opportunity for companies to reduce their carbon footprint. To help industries in their sustainable and circular transition from internal combustion engine production to electric motor production, the deployment of a sound environmental impact assessment methodology, such as life cycle analysis (LCA), coupled with Design for Re-X tools, such as circularity indicators, is instrumental. To demonstrate the industrial relevance and complementary of both approaches, two consecutive workshops are conducted with a major original equipment manufacturer of recreational boats and their associated engines, in the United States and Europe. These workshops were designed and operated by two sustainable design experts in industrial engineering, and were attended by the principal industrial stakeholders and actors in the design and development of electric outboards, including, e.g., two materials engineers, the technical lead, the reman general manager, and the director of sustainability engineering programs. The first half-day session, focused on LCA, aimed to showcase how to calculate the environmental impact of their new electric outboard, in order to identify environmental hotspots and quantify potential savings (e.g., from material alternatives or circular economy loops). The LCA results showed close to an equal distribution of carbon emissions allocated between the manufacturing phase and the usage phase, highlighting the importance of both Re-X solutions (such as increased recycled content or remanufacturing) and the efficiency of the battery, motor, and propeller to mitigate its carbon footprint. On this basis, during the second half-day session, two circularity indicator-based tools were used to assess (i) the circularity potential of the electric outboard as a whole, and (ii) the circularity performance of two critical components, the electric motor, and the lithium-ion battery. In all, the practice sessions generated eleven ideas to improve the circularity of the electric outboard. As the participants found both frameworks easy to use and efficient, all the details and resources used to conduct, replicate, or adapt such workshops in various industrial setups will be shared.

1.P.06 Preliminary Results of the Environmental Behavior of Using Encapsulated Phase Change Materials in Thermal Energy Storage

Daniel Garrain[1]*, Chatura Wickramaratne*[2]*, Samantha Wijewardane*[2] *and Yogi Goswami*[2]*, (1)Energy, CIEMAT, Spain, (2) Clean Energy Research Center, University of South Florida, United States of America*

Thermal energy storage using phase change materials (PCM) has been thoroughly demonstrated as being capable of storing and releasing large amounts of energy. For high temperature applications, various salts have been proposed as low-cost PCM. However, there are concerns about salts as PCMs because of corrosion issues within the storage tanks and their low thermal conductivity and high reactivity above 500ºC; hence the compatibility of the PCM-tank pair plays an important role in the design of this type of facilities. Encapsulation of the salt based PCM has been proposed as a way to address these concerns. Another advantage of using PCM capsules is the reduction of tank infrastructure since it allows the use of a single tank instead of two for hot and cold molten salts. Therefore, encapsulation processes provide many benefits from the techno-economic point of view. This study presents the preliminary results of an additional assessment from an environmental approach, by application of the Environmental Footprint method, in order to analyze the environmental aspects using different materials as capsules. Moreover, this study proposes several recycling scenarios for completing the life cycle analysis of encapsulated thermal energy storage.

1.P.07 Material Flow Analysis and Life Cycle Assessment of Materials Needed by Electric Vehicles Using the Method of Multi-regional Environmentally-extended Input-output Analysis

María del Pilar MARTÍNEZ Hernando[1]*, David Boloni*[2]*, María Jesús García Martínez and Marcelo Fabián Ortega Romero, Universidad Politecnica de Madrid, Spain*

Clean technologies are rapidly increasing in the last decade. In the transport sector, market share of global electric car sales has changed from 0.0 % in 2010 to 3.2 % (2.1 million) in 2020, and predictions show that sales could reach near 30 % in 2030. This drastic change is mainly encouraged by environmental goals set to reduce CO2 emissions, not emitted by electric vehicles (EVs) during the use phase. However, clean technologies might cause other impacts during manufacture and, while clearly reduce the dependency on oil, can increase the dependency on other materials. In this context, the objectives of our work are quantifying the environmental impacts and supply risk of lithium, neodymium and cobalt, metals needed by EVs and considered Critical Raw Materials by the European Union. A Multi-regional environmentally-extended input-output analysis is the key framework to perform a Material Flow and Life Cycle Assessment. This method quantifies the material´s origin, the produced impacts and the country where the impacts are being produced, in contrast to conventional methodologies that only calculate global impacts. Therefore, environmental impacts are estimated considering different scenarios, based on environmental objectives of the European Union and China. In most scenarios China shows a key role in mining and processing of metals, being the country where major impacts are produced. Obtained results are useful to assess which environmental proposals are more effective to reduce the environmental impact of EVs and set the ground to understand the geostrategic importance of key metals used for EVs manufacture.

2 Resource Efficiency in Production

2.01 Environmental Impact of Recycled Polymer in Aeronautics. ECOCLIP Project

*Raquel Travieso, Santiago G. Cuervo, Celia Martín and **Rocio Pena**, AIMEN, Spain*

In ECOCLIP project, recycled processes were developed for aeronautical high-grade polymers reinforced with carbon fiber (i.e. LMPAEK-CF). It would be an improvement in the End of Life of airplanes and increase materials circularity in the sector. In order to demonstrate environmental benefits a comparative LCA was carried out following ILCD handbook and ISO14040 methodology. The LCA has been approached considering that the demonstrators (high-value aircraft structural components) were obtained from recycled and developed from raw materials LMPAEK-CF in comparison with current aluminium metal-working ones. Injection molding and 3D printing were considered for the manufacturing of components. During the project, it has been possible to generate a new material composed of 60% recycled material from manufacturing leftovers and 40% virgin material. Although during the project only factory waste was used, results showed that EoL material could be considered continuous carbon fiber thermoplastic composites start to be a common material in sector. Cradle to door scope was considered in order to evaluate manufacture and raw materials impact. But also, a cradle to grave analysis was contemplated to evaluate weight reduction during the use of the airplane in the case of aluminium substitution. Results from cradle to door analysis showed, if developed from raw and recycled LMPAEK-CF were compared, it could be possible a 5% reduction in environmental impact (Pt in ILCD endpoint methodology) and 20% carbon footprint reduction comparing results for injection moulding manufacturing. In the cradle to grave analysis, it is possible to validate that environmental impact is minor due to component weight reduction, when raw material is changed from metal to polymer. In the ECOCLIP case-study, this reduction is 30% in environmental impact and 65% of carbon footprint when it is compared injection moulding of recycled material with aluminium components. In the case of developed from raw LMPAEK-CF vs recycled the reduction is less than 5% in environmental impact.

In conclusion, the project demonstrates improvement in using recycled CF-thermoplastics in aeronautics. Moreover, weight reductions for material change (CF-thermoplastic vs metal) compensate for the higher impacts in the manufacturing phase, due to during the use phase is expected less fuel consumption and consequently combustion gases emissions.

2.02 Calculation of Technical Substitutability Coefficients in Waste Management Life Cycle Assessment Studies

Lucia Rigamonti[1]*, Sue Ellen Taelman*[2]*, Sophie Huysveld*[2]*, Sophie Sfez*[2]*, Kim Ragaert*[3] *and Jo Dewulf*[2]*, (1)Department of Civil and Environmental Engineering, Politecnico di Milano, Italy, (2)Green Chemistry and Technology, Ghent University, Belgium, (3)Centre for Polymer and Material Technologies, Ghent University, Belgium*

Life Cycle Assessment (LCA) is a widespread tool used to guide decision-makers towards optimal strategic choices for sustainable growth. A key aspect of LCA studies of waste management systems where recycling activities are present is to account for resource recovery and the related substitution effects. When the LCA analysist wants to apply the approach called “system expansion with substitution” or “avoided burden method”, he/she has to identify and model mono-functional processes external to the system under study, which yield products or functions that are equivalent to those of the co-products of the considered multi-functional process. These inventories are commonly subtracted from the inventory of the original multi-functional process in order to estimate the inventory associated with the co-function of interest. However, quantifying the extent to which products are functionally equivalent and intersubstitutable is a difficult task. Although multiple scientific papers assume a 1:1 substitution ratio between similar materials/products, this is often incorrect as the actual ratio is likely to vary. The focus of this presentation is on the calculation of the substitutability coefficient for secondary materials based on technical characteristics. A state of the art literature review showed that many different calculation procedures were applied, which led to a wide variety of substitutability coefficients. In this perspective, the objective of this presentation is to provide guidelines on the procedure to be followed to calculate the substitutability coefficient for secondary materials, based on the learnings from previous studies. In particular, departing from the framework proposed by Vadenbo et al. in 2016, the focus in this presentation is on the technical functionality of the materials as a basis for calculating the substitution coefficient. These guidelines are then applied to two waste management case studies.

In total, sixteen technical substitutability coefficients are given for ten secondary materials, based on state of the art and presented case studies. The research thus represents a step forward in quantifying the substitutability of secondary materials in waste management LCA studies. The guidelines presented may allow other case studies to enrich the list of coefficients, useful for all LCA practitioners to evaluate in a more correct and harmonized way the environmental impacts associated with recycling activities.

2.03 Abiotic Resource Impacts in a Circular Economy Context: Indicator Methods and Modelling Approaches

Georgia Psyrri *and Thomas Astrup, Environmental and Resource Engineering, DTU (Technical University of Denmark), Denmark*

In the past few years, Circular economy (CE) has emerged as a promising concept where resource circles are closed or retained for as long as possible through a wide range of strategies. Although LCA offers a consistent and systematic platform for assessing the environmental consequences of circular solutions, the lack of attention to resource indicators in a circular economy context, risks supporting a situation where more attention is placed on climate impacts than resource impacts. This may limit the applicability of LCA for circular economy and ultimately lead to false conclusions in relation to resource impacts.

The aim of the study is to increase the understanding of LCA resource indicators and by extension, improve the interpretation of results of studies conducted in a circular economy context. In particular, the following research questions are assessed: How do i) modelling choices in LCA and ii) the choice of LCIA method affect the interpretation of results. An LCA is performed on a case study focusing on recycling scenarios that address the full life cycle. Thereon, the implications of integrating technospheric parameters in the context of circular economy are contrasted by the selection of different abiotic resource indicators at midpoint level. An overview of responses of the different resource indicator types in relation to recycling scenarios is presented. Results are discussed in respect to critical aspects such as resource coverage, double counting, by-product dependencies and time frame inconsistencies. Based on the results, areas of concern are highlighted along with recommendations for LCA practitioners with respect to selection of appropriate indicators and interpretation of results.

2.04 Characterizing Abiotic Resource Services Deficit

Titouan Greffe[1]*, Manuele Margni*[2] *and Cécile Bulle*[3]*, (1)CIRAIG, Canada, (2)Mathematical and Industrial Engineering*

Department, Polytechnique Montreal, CIRAIG, Canada, (3) Department of Strategy and Corporate Social Responsibility, ESG, UQAM, CIRAIG, Canada

Abiotic resources provide multiple services to humans. The resource services provided to humans can be considered as the anthropocentric instrumental values of resources, which is defined as the Area of Protection (AoP) "Natural Resources" as per the consensual definition elaborated by the UNEP-SETAC Life Cycle Initiative[1]. Humans benefit from services provided by the resources, but so far no life cycle impact assessment method has been developed to assess the specific impact pathways leading to a deficit of resources services. This research work aims to fill-in this gap and assess impacts to human society from the deficit of resource services. Building upon the conceptual framework from Greffe et al. (2022)[2], CARSeD assesses the deficit of resources services for humans and then the impact to human society in term of adaptation cost. The deficit of services is assessed as the mismatch between the provision and the demand. The prospective demand of resources is evaluated by coupling a material flow analysis model with an integrated assessment model. The potential impact of the use of a given resource (through its life cycle encompassing extraction, dissipation and occupation) is calculated from the deficit of services between demand and provision. Degradation of resource is also evaluated as the difference of functionality between the flows of resource entering and leaving the product system. Finally, the damage is calculated as the cost to pay to recover the deficit. Preliminary characterization of intermediary and elementary flows of resources have been determined for aluminium and will probably be determined for iron, copper, nickel, indium and zinc. The elementary flows characterized are the extraction of resources from the ecosphere and the dissipative flows back to the ecosphere. The intermediary flows characterized are newly introduced occupation flows, that are distinguished by their potential to fulfill services. The comparison of functionality between resource flows enables the impact assessment of degradation or restoration. An exploratory operational impact assessment method is now available to assess resources services deficit and will soon be generalized to other resources.

[1] https://doi.org/10.1016/j.jclepro.2017.05.206

[2] Greffe, T., Margni, M., Bulle, C., 2022. A framework for assessing abiotic resources services deficit in life cycle impact assessment (under review). Int. J. Life Cycle Assess.

2.05 An Absolute Sustainability Approach for Holistic Planning of a Product Fabrication with Additive Manufacturing

Valentina Pusateri *and Stig Olsen, Department of Environmental and Resource Technology, DTU (Technical University of Denmark), Denmark*

In the last decade, the concept of absolute sustainability, intended to represent the need to develop a prosperous society in respect of the Earth´s carrying capacity, has been widely investigated by academics and adopted by a few major European manufacturing industries. At the same time, companies and researchers recognized the potential of additive manufacturing (AM), both in terms of lean manufacturing, lightweight design, and increased product functionality optimization. Since the manufacturing sector constitues a high-carbon economy and contributes to about a quarter of the industrial carbon emissions worldwide alone, AM's potential for energy and carbon emissions savings during product life cycle should be investigated. To reduce the overall impact of the manufacturing sector, it is essential to develop a holistic framework that simultaneously mitigates its environmental impact and increases resource-use efficiency. This is the main aim of this paper. We developed a framework that combines Material Flow Analysis (MFA) and Life Cycle Assessment (LCA) for assessing the sustainability potential of additive manufacturing processes in terms of circular economy (CE) at the product level and applying an absolute sustainability perspective. LCA adopts an assessment that is based on existing products or systems in a retrospective manner. On the other hand, manufacturing process planning, and CE strategies need to be investigated and decided upon prior to a part fabrication. Thus, they are more prospective. To fill this gap, a scenario analysis was applied to a product produced with Wire Arc Additive Manufacturing (WAAM). The scenario assumptions were based on the likely design and application of the manufacturing process. Overall, combining (1) Life Cycle Assessment (LCA), (2) Material Flow Analysis (MFA), and (3) circular economy (CE) for scenario analysis of a specific component fabrication through additive manufacturing showed potential to aid decision-making for companies. In particular, the framework could be used as a support tool for holistic production planning by avoiding burden-shifting and highlighting trade-offs in choosing the best circular economy strategies.

2 Resource Efficiency in Production (Poster)

2.P.01 Environmental and Social Impact Assessment Focusing on Mineral Resources and Fossil Fuels for Multiple Vehicle Types (ICEV, HEV, EV)

Sayaka Kakiuchi *and Norihiro Itsubo, Tokyo City University, Japan*

Transportation accounts for about 16% of global greenhouse gas emissions, with passenger cars emitting the largest amount of CO2 compared to others. As the need to reduce CO2 emissions from transportation increases and gasoline regulations in many countries progress, electric vehicles (EVs) are expected to spread rapidly. EVs require batteries, and the demand for the mineral resources needed to manufacture batteries is expected to increase even further. Currently, NCM (nickel, cobalt, and manganese) is the main battery component, with more than 50% of cobalt production coming from the Democratic Republic of Congo (DRC). 40,000 children are estimated to be involved in mining in the DRC, where child labor, low wages, and work hazards (dermatitis, breathing problems, etc.) are reported. diseases, etc.) have been reported. To achieve sustainable development, it is necessary to create products that take into account not only environmental but also social risks. In automotive LCA, many studies focus on the environmental aspect in particular, and the results vary depending on preconditions such as vehicle type and lifetime mileage. In terms of the social aspect, there are some papers on lithium-ion batteries using social databases, but there are no papers that evaluate the life cycle of automobiles, nor are there any papers that compare databases with each other.

The purpose of this study was to present the characteristics of both environmental and social impact assessments for three vehicle types (ICEV, HEV, and EV), and social impact assessments using the Social database. In the environmental impact assessment, the number of environmental emissions and resource consumption were calculated, and then the amount of environmental damage was estimated and converted into monetary values by performing a Life Cycle Impact Assessment

(LCIA) using LIME3. As a result of the environmental impact assessment of three vehicle types (ICEV, HEV, and BEV), the impact of fossil fuels in the use stage was the largest for ICEV and HEV, while the environmental impact of mineral resources in the manufacturing stage was the largest for the the EV. On the social side, for example, focusing on child labor, the risk is highest in the process of producing lithium-ion batteries in China, and if the procurement of raw materials is limited to low-risk countries, the risk time will be significantly reduced.

2.P.02 Creating Sustainability Value Propositions Through Material Development and Product Redesign – a case study of thermally conductive polymers in industrial applications

Anju Baroth, PhD[1]*, Avantika Shastri*[1]*, Karishma Tijoriwala*[1]*, Chinmaya Dandekar*[2]*, Shahab Zekriardahani*[3] *and Javed Mapkar*[4]*, (1)Centre for Sustainability, Eaton Research Lab, Eaton, India, (2)Centre for Digital Design, Eaton Research Lab, Eaton, India, (3)Eaton Research Lab, Eaton, United States of America, (4)Advanced Materials & Processes, Eaton Research Lab, Eaton, United States of America*

Cost, performance, and safety are the most crucial factors in material selection with recent addition of sustainability and environmental performance. In product design and optimization, material choice is crucial, and novel advanced materials can have positive influence on the product as well as environmental performance. Design for Environment (DfE) is an integral part of product design at Eaton where we consider environmental performance alongside cost, safety, business, and technical excellence in decision making. Here we present this through a case study on novel thermally conductive polymers used for optimized and redesigned enclosure for an industrial bay lighting and compared Aluminium alloy enclosure. Electrical enclosures for harsh and hazardous industrial environments must meet strict chemical and corrosion resistance, safety, and thermal conductivity standards. Typically made of coated metals, these can corrode in such environment and are also heavy to handle. Eaton's advanced materials research program developed a novel thermally conductive polymer (TCP) formulation with enhanced mechanical properties & corrosion resistance allowing enclosures to be light weight, design flexibile and lower system costs than conventional aluminium-based metallic enclosures. The optimized design was over 50% lighter and met or exceeded technical and cost targets. We applied our DfE approach, where we use qualitative and quantitative tools such as Eaton's Positive Impact Framework, chemical screening, and comparative life cycle assessment (LCA), alongwith material and product development ensuring enhanced sustainability performance of new product. In this project we conducted an ISO 14040/44 compliant, critically reviewed Cradle-to-Grave LCA. Results show that lighter TCP product had a 27–34% lower Global Warming Potential (depending on EOL scenarios), and 5–64% lower environmental impacts across other impact categories. Insights from the study were used to evaluate various potential applications for the new TCP material, including design targets for light weighing, key process yields, end-of-life scenarios and opportunities to further reduce the novel material's environmental impact. The innovation presented here and its associated LCA study prove that businesses must apply DfE and embrace sustainability, and that companies can gain considerable sustainability benefits coupled with technical and cost benefits through novel material innovations and product redesign.

2.P.03 Simplex Lattice Design in Optimizing Fossil Fuel Blends for Sustainable Desalination: Al Life Cycle Assessment

Esra Eisa Aleisa[1] *and Reinout Heijungs*[2]*, (1)Industrial and Management Systems Eng, Kuwait University, Kuwait, (2)Vrije Universiteit Amsterdam, Netherlands*

This study applies life cycle assessment (LCA) to evaluate, analyze and optimize the effects of different fuel mixtures on sustainability. An augmented simplex lattice mixture (ASLM) design is used to identify the points at or experimental conditions under which the different life cycle inventories (LCIs) are examined and life cycle impact assessment (LCIA) responses are measured. ASLM design is applied to legitimate analysis, results and conclusions given the correlation due to collinearly inherited from the nature of the fuel mixture problem constraints. Regression models are formulated to represent LCIA results in a closed form suitable for analysis of response surface methodology (RSM) optimization. The LCIA response surfaces are interpreted statistically using hypothesis testing and graphically using contour and Cox trace plots. For each mixture, an overall composite sustainability index (CSI) is calculated by aggregating and normalizing corresponding LCIA responses of different units, ranges and scales, then optimized using and RSM-based method. On a national-wide scale a 17% reduction in associated environmental impacts can be realized while incurring a minor retrofitting cost. Which is substantial, given that more than half of the oil production in Kuwait is consumed by co-generation for power desalination plants.

2.P.04 Increasing Resource Efficiency in the Mining Industry: Sustainability Assessment of Grecian Magnesite Case Study

Lucia Rigamonti[1]*, Hazem Eltohamy, MSc*[2]*, Giuseppe Cecere*[3]*, Haris Yiannoulakis*[4] *and Duong Hoang*[5]*, (1)Dep of Civil and Environmental Engineering, Politecnico di Milano, Italy, (2) Civil and Environmental Engineering, Politecnico di Milano, Milan, Italy, (3)Politecnico di Milano, Italy, (4)Grecian Magnesite, Greece, (5)Maelgwyn Mineral Services Ltd, United Kingdom*

Separation by flotation is one of the common technologies used during beneficiation stage in mining industry, aiming at concentrating valuable minerals for downstream refining stages. Currently a new froth flotation technology is being developed under FineFuture (FF) project, funded by the European Union Horizon 2020 research and innovation programme (grant agreement No 821265). If implemented, this technology can valorise fine mineral particles instead of discarding them as residues, nevertheless this does not necessarily ensure the sustainability of the technology. To verify this, a sustainability assessment has been performed for one of the project case studies, i.e. the one that involves the industrial partner Grecian Magnesite (GM). GM is a Greek mining company specialized in magnesite concentrate ($MgCO_3$) and magnesia production (MgO). The beneficiation plant under study is in Yerakini Mines and Works in Chalkidiki, Greece. The aim of the sustainability assessment is the comparison between the current beneficiation system of GM with the future one that will have FF flotation implemented on full scale to benefit from the very fine particles with granular size < 4 mm that are currently discarded as waste. The sustainability assessment has been performed considering the three pillars of sustainability. For the environment, a comparative Life Cycle Assessment (LCA) has been carried out, whereas the Material Flow Cost Accounting (MFCA) methodology has been applied to evaluate the economic costs. To assess the potential social risks that must be tackle when implementing the new technology, a Social Hotspot analysis has been carried out, taking into account the Other Mining and Quarrying sector in Greece (NACE rev. 2) and using the PSILCA database. The presentation will show the main results of the assessment, together with the challenges of an evaluation of this type, both technical and methodological: in fact, both the technology under assessment and the methodology itself for the assessment are still under development.

2.P.05 Environmental Impact of Metal Additive Manufacturing in the Aeronautical Sector

***Rocio Pena**, Aurora Lopez, Paula Villar and Gemma Castro, AIMEN, Spain*

Additive manufacturing processes are relatively new and their environmental benefits are still unclear, as they are highly dependent on the technology to be used, the materials that form part of the process and the degree of environmental impact of the manufacturing processes being compared. In this sense, quantifying which aspects of an additive manufacturing process have the greatest environmental impact allows prioritizing actions to improve their sustainability. AM is considered more adequate for complex geometric and short series, so it is widely used in aeronautical industry. The AM process studying in this work consists in a laser metal deposition (LMD) using aluminium alloy powder (scalmalloy). As example an aeronautical component was considered and compare new AM process with conventional metalworking process, so that not only manufacturing process was analysed (cradle to door), also possible reduction weight during use phase was considered (cradle to grave). AM allows more complex geometrics that reduces components weight resulting for a more efficiency redesign. Furthermore, current machining process have an excess of scrap waste, due to obtain desired mechanical properties, it is needed to start with a solid block of the total volume of the component. In order to demonstrate environmental benefits a compared LCA were carried out following ILCD handbook and ISO14040 methodology. LCI were obtained in laser process research activities carried out in by AIMEN.

The results of the LCA corroborate the benefits of additive manufacturing in the case of components with complex geometries; a significant reduction in material use offsets the greater impact of higher energy consumption in the processes. For the particular case of the component studied, this reduction represents for the cradle-to-gate analysis 44% for the carbon footprint and 73% for the total impact (Pt using ILCD methodology). The main impact in both cases is raw material (aluminium alloy and scalmalloy powder). The reduction in weight of the component is reflected in a reduction of the entire life cycle, of the carbon footprint by 20% and of 76% for the final impact.

As conclusion, AM could reduce environmental impact in aeronautical sector, with a reduction of raw materials in manufacture and allowed complex geometries with reductions in weight.

2.P.06 The Puzzling Scenario of Carbon Fibre Composite Production and the Rabbit Hole of Life Cycle Assessment (LCA) Data

*Juliana Steinbach and **Sinead Mitchell**, Mechanical Engineering, National University of Ireland Galway, Ireland*

Life cycle assessment (LCA) is the leading methodology to estimate lifetime impacts of products and processes. The foundation underpinning LCA is data about the process, known as Life Cycle Inventory (LCI). Carbon fibre (CF) composites have an important role to play in the substitution of mainstream materials (e.g. steel and aluminium) in the transportation sector. Light-weighting using CF as a substitute reduces weight and consequently energy and fuel savings during the use phase of automobiles and aircrafts. However, CF manufacturing is an energy intensive process due to the high temperatures required during the carbonizing step. Therefore, it is not straightforward to assume the environmental advantage and emissions reduction associated with composite applications. Scientific journals, magazines and industry associations have published data for CF and composite production. However, critical information about the process is usually not disclosed publicly. The lack of transparency from industrial sources is a major barrier to LCA practitioners eager to conduct an accurate and reliable comparative assessment when CF is a material in the model. Moreover, tracking the source of information in scientific publications is complex and frequently results in a circuitous map of repeated data from different authors. This study investigates and maps this CF data network in the published literature to understand the quality and transparency level of current data and reports on the primary and secondary sources of production and process data available.

This work has revealed a series of interrelated scientific publications and connected the dots that underpin this network of studies to create a visual map of published CF data. The map identifies and centralizes direct and indirect sources associated with them. Each central data is further categorized based different levels of transparency and quality in terms of temporal, geographical, technological and process completeness. This graphic will provide a more straightforward way of selecting the appropriate data for CF LCA and disclose the related gaps in the literature. Better transparency will allow for reproducibility and promote non-biased evidence to inform decision makers and contribute to improved reliable studies involving CF as a material.

3 Circular Economy & Challenges in LCA

3.01 Tracking Environmental Consequences Over Space and Time of Material Circularity Strategies

***Jean-Martin Lessard**[1], Guillaume Habert[2], Arezki Tagnit-Hamou[3] and Ben Amor[1], (1)LIRIDE (Interdisciplinary Research Laboratory on Sustainable Engineering and Ecodesign), Université de Sherbrooke, Canada, (2)Departement of Civil, Environmental and Geomatic Engineering, ETH Zurich, Switzerland, (3)Department of Civil and Building Engineering, Université de Sherbrooke, Canada*

Assessing the environmental implications of new material circularity strategies requires simulating the direct and indirect market responses across far-reaching and competitive industrial symbiosis. However, existing life cycle assessment modeling capabilities oversimplify these large-scale adjustments in production-consumption-waste chains and trade patterns with linear assumptions (i.e., one unit of recycled material replaces one unit of virgin material). This study aims to build such capacity through enhancing consequential life cycle assessment with a least-cost circular economic optimization model. The latter simulates the competition in the mutual exclusive supply streams of virgin, recovered and waste materials across six regions and seven industries, while considering their costs (processing, transportation), market saturation, and availability. Affected flows (i.e., the difference between the optimized market states with and without the material circularity strategy) are characterized in terms of potential damage to human health, ecosystem diversity, resource availability and impact on climate change using the ecoinvent "consequential system model" and ReCiPe 2016. The model is used to assess and compare the environmental consequences of two material circularity strategies for recovering post-consumer glass in the province of Quebec (Canada): the improvement of closed-loop bottle-to-bottle systems and the deployment of open-loop systems for producing glass powder as cementitious material. In both systems, results highlight non-linear phenomena as new secondary material supplies in Quebec displaced not only local virgin materials but also other competing secondary materials (e.g., cullet or fly ash) from Midwest and Northeastern United States. Indirectly, the surpluses induced in these markets are redirected to other undersupplied markets, which thereby reduces their need for virgin materials. Consequently, between 55% and 94% of the environmental benefits falls beyond Quebec's jurisdictional boundaries. This suggests that linear assumptions of conventional models may result in misleading environmental consequences associated to new material circularity strategy. Thus, the development of the proposed modeling can help decision makers achieve a more sustainable economy by providing a more accurate picture of the potential impacts of material circularity on trade, consumption, and production of materials and, ultimately, on the environment.

3.02 Assessing Linear and Circular Plastics Recycling with Basket of Functions

Rickard Jansson[1], Tomas Rydberg[2], Emma Moberg[2] and ***Tomas Ekvall****[3], (1)Swedish Plastic Recycling, Sweden, (2)IVL Swedish Environmental Research Institute, Sweden, (3)Tomas Ekvall Research, Review & Assessment, Sweden*

The Extended Producer Responsibility in Sweden specifies that 90% of PET bottles and 50% of plastic packaging should be recycled, but with no account for the quality of the recycled material. This policy target is easier met by grinding waste plastics together and putting a low-quality product on the market, than by advanced sorting and recycling to replace new packaging material. We calculate the climate impacts of a system where 50 % of used plastic packaging is recycled into new packaging. We compare this to a more linear system, where the packaging material is downcycled into railway sleepers that are incinerated after use. The comparison is made with different methods for modelling recycling: cut off and expansion into a basket of functions. The basket of functions can, in turn, be based on the functions generated by the unallocated packaging life cycle, or by the unallocated life cycle of the plastic material. The latter includes multiple packaging cycles, or the life cycle of a packaging and a sleeper. The cut-off approach does not reflect the benefits of recycling. A product-based basket of functions reflects the climate benefits of recycle rather than downcycle a piece of packaging. A material-based basket of functions reflects the climate benefits of establishing a recycling system rather than a linear downcycling system. The latter is most relevant for policymaking. The results indicate much less climate impact for 50% recycling, compared to 50% downcycling. The difference is less, but still significant, when the options are applied to an externally given collection ratio for plastic waste. The benefit of circular recycling is also sensitive to the efficiency of the advanced sorting. A policy instrument that stipulates a volume of recycling without accounting for the quality of the material clearly does not adequately address the environmental benefits of recycling. We discuss policy changes that can stimulate circular recycling, rather than downcycling.

3.03 Environmental Impact Associated with the Use of Blockchain in the Circular Economy

Benedikt Völker[1], Alice do Carmo Precci Lopes[2] and ***Tabea Hagedorn****[2], (1)TU Darmstadt, Germany, (2)IWAR / SuR, TU Darmstadt, Germany*

The core of the Circular Economy can be translated into closing material loops, avoiding the extraction of raw material and contributing to a climate neutral society. However, closing material loops requires an efficient, secure and transparent information exchange among the different stakeholders of the Circular Economy. Currently, delivery of information about quantity and quality of by-product / waste generated by an industry occurs often bilateral by email. This form of information exchange impairs an efficient and standardized communication, especially when different stakeholders should be integrated and interact with each other. The Blockchain technology is a promising solution for bridging the different stakeholders of the circular economy. It is a decentralized system, which provides a high level of security and transparency and allows that a high number of stakeholders interact with each other. This efficient interaction among the stakeholders enables that the final disposal of materials are avoided, being returned to the market. However, the Blockchain technology has been associated with bitcoin mining, which counts with high energy demand and negative environmental impacts. The environmental impacts of the Blockchain technology for improving the circular economy still needs to be investigated, especially for the exchange of information.

This study aims at investigating the environmental impacts associated with the use of the blockchain technology for a specific case study in Germany. A life cycle assessment of the exchange of information via Blockchain technology is conducted and compared with the current form of information exchange. This is an on-going research and the results are expected to be delivered soon.

3.04 Life Cycle Assessment of Anode Recycling in End-of-Life of Solid Oxide Cells

Rok Stropnik[1], Andrej Lotric[1], Jure Gramc[1], Sonia Fiorilli[2], Sofia Saffirio[2], Federico Smeacetto[2], Sergii Pylypko[3], Sabina Fiorot[4], Silvia Fiore[5] and ***Mitja Mori****[1], (1)Department for energy engineering, University of Ljubljana, Faculty of Mechanical Engineering, Ljubljana, Slovenia, Slovenia, (2)Department of Applied Science and Technology, Politecnico di Torino, Torino, Italy, Italy, (3)Elcogen, Tallinn, Estonia, Estonia, (4)Environment Park S.p.A., Torino, Italy, Italy, (5)Department of Environment, Land, and Infrastructure Engineering, Politecnico di Torino, Italy, Italy*

The European Green Deal forms the basis for a series of progressive energy policies and long-term strategies set out in the New Circular Economy Action Plan, which aims to achieve a carbon-neutral EU by 2050. In this transition, fuel cell and hydrogen (FCH) technologies will play an important role, and among them, solid oxide cells (SOFC and SOEC) offer an efficient and fuel-flexible technology as an alternative to fossil fuel-based technology. On the other hand, SOCs consist of critical raw materials (CRMs) and rare earth elements (RRE), which are very important for the EU not only from a geostrategic and economic point of view, but also from an environmental sustainability point of view. To reduce the consumption of virgin CRMs, RREs to enable more sustainable SOC technology, specifically designed End-of-Life (EoL) strategies must be defined and implemented for the recovery of materials from old SOCs, which are non-existent and so this is the main objectives of the EU Best4HY project.

In this study a detailed life cycle inventory (LCI) analysis of a multi-step EoL processes aimed at the material recovery from the SOCs (fuel electrode - YSZ, Ni), dismantled from the stack after end of operation. The LCI was created step by step for all processes, so that the LCA model can be easily adapted after scaling up from the laboratory scale. The functional unit is 1 gram of the recovered material (YSZ, Ni). The LCA methodology was used with environmental footprint 3.0 impact assessment methodology, focusing on FCH relevant impact indicators (e.g., climate change, resource use, acidification). The Best4Hy SOC recycling results are currently the focus of interest in the FCH recycling industry, as these presented LCI data results for all modelled processes are a first in the field. The LCI data results and LCA model are available for the first time with an additional environmental impact assessment and comparison of closed loop (within SOC technology) and open loop (to other possible technologies) recycling to show possible cross-sectional effects on reducing the environmental impacts.

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) under Grant Agreement No 101007216. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation program, Hydrogen Europe, and Hydrogen Europe Research.

3.05 CarboxyLCA: Computer-aided Design Tool for Fostering the Valorization of Food Waste and Side Streams into Carboxylates

***Mateo Saavedra del Oso**, Alberte Regueira, Almudena Hospido and Miguel Mauricio-Iglesias, Cross-disciplinary Research Center in Environmental Technologies (CRETUS), Department of Chemical Engineering, Universidade de Santiago de Compostela, Spain*

The carboxylate platform has the potential to constitute an excellent opportunity for resource recovery from food waste and side streams within a circular economy framework. However, its development is still hindered by technological constraints as predicting the volatile fatty acids (VFA) yields from different wastes. Furthermore, the validation of a better life-cycle environmental and economic performance than the current waste treatments is needed to unlock its deployment. Therefore, this work aims at overpassing those development barriers and boosting the resource recovery into added value products. The framework is implemented as a computer-aided design tool, which originally comprised three modules and here expanded to five to assess both economic and environmental performance: (i) a library of substrates including their characterization and appropriate kinetic parameter selection; (ii) an integral kinetic and stoichiometric model which solves the constraints regarding the disintegration mechanisms and the acidogenic stoichiometry variability in the mono(co)fermentation; (iii) a life cycle inventory (LCI) module which upscales and transforms the model outcomes into LCI inputs and outputs; (iv) an environmental and economic evaluation module which transforms the LCI items into environmental impacts and capital and operational costs; (v) an interpretation module which converts the outputs of module into decision-support indicators.

Preliminary results from different case studies on regrind pasta, fish processing wastewater and a mixture of the latter, show that energy required for heating the system and NaOH addition (when operating at neutral/basic pH) are the main environmental and economic hotspots. However, the environmental burdens of these activities also depend on the time horizon and the background scenarios. Besides, the substrate composition and the pH determine the products yield and thus, affect both environmental and economic performance. This tool can solve supply chain problems, e.g., screening a portfolio of wastes and providers to obtain a suitable VFA mixture that it is further transformed into polymer material with specific properties. This work proves that computer-aided design tools can help to assist the decision making at different stakeholders' levels, identifying technical bottlenecks, and proposing innovative solutions prior to expensive lab research and piloting.

3 Circular Economy & Challenges in LCA (Poster)

3.P.01 Accelerating Life Cycle Modelling – How to reduce data acquisition workload in GHG accounting

***Julian Baehr** and Liselotte Schebek, TU Darmstadt, Germany*

By passing the European Green Deal the European Union committed to achieving greenhouse gas (GHG) neutrality by 2050 (European Commission, 2019). Achieving GHG neutrality requires correct, consistent and holistic quantification of emitted GHG which has been acknowledged by recent international legislation (e.g. Paris Agreement). Still, GHG accounting remains a daunting task. Since GHG accounting can and should be performed on different scopes (products, services, companies and states), data sources vary making data acquisition highly complex (Eurostat, 2015; GHG Protocol, 2021; IPCC, 2006; ISO, 2006). To accelerate the data acquisition process, today high hopes lie on novel information technologies (IT) like machine learning (ML) and automatization of data collection, sorting and preparing (Pagano & Krause, 2021).

Therefore, this work covers the following research questions:
-Which data sources for GHG accounting exist and what are their underlying accounting methodologies and political instruments, respectively?
-How do existing data sources relate, interact and possibly overlap?
-What are possible application fields for novel IT solution to help accelerate GHG data acquisition?

International political instruments requiring GHG reporting on different scopes (e.g. Paris Agreement, Non-financial Reporting Directive) are analyzed with regard to required data sources. In a structured analysis existing data sources are classified and overlapping data as well as data gaps are identified. This way, a web of data interactions is developed, which discloses data constraints but also opportunities for the use of intelligent IT.

The web of data interactions discloses that data from one data

source is often used to comply with multiple political instruments. For example, emission data from a production facility is used to comply with political reporting on corporate, facility and product level.
Therefore, the use of intelligent data sorting and preparing could enable automated compliance with all these political instruments.

Identifying data sources which can be used for GHG reporting on multiple scopes could drastically reduce data acquisition workload. Here novel IT solutions could unfold tremendous potential to accelerate GHG accounting.

3.P.02 Are We Answering or Asking the Wrong Questions, When Using LCA in the Built Environment?

Sarah Cecilie Andersen[1]*, Harpa Birgisdottir*[2] *and Morten Birkved*[3]*, (1)Buildings & Environment, Danish Technological Institute, Denmark, (2)Department of the Built Environment, Aalborg University, Denmark, (3)SDU Life Cycle Engineering, Department of Green Technology (IGT), University of Southern Denmark, Denmark*

When introducing Circular Economy (CE) into the Built Environment (BE), we're also introducing inherently more complex questions and assessment scales, than what has previously been known and applied in the Business-As-Usual (BAU) economy. LCA has, to a large extend, been introduced to the BE through European Norms (EN), i.e., EN15804 and EN15978. However, these are not necessarily developed to answer questions of the complexity scale as entailed by CE, but are the LCA assessors in the BE aware of these potential complexity risks, and have we been biased by a simplified (product assessment oriented) solution, as prescribed by the norm? The authors set out to investigate whether the questions asked when applying LCA for assessment of CE in the BE, were interchanged from the questions asked in BAU LCA. The study investigated what answers were interpreted from case study results, and the inclusion of BE complexities such as long lifespans, along with the added complexities of introducing CE, such as interaction of solutions across industries, socioeconomic developments, and future societal development pathways. The study resulted in a review, containing 84 scientific papers, containing at least 1 case study on the BE.
The review finds that most studies, even though assessing CE approaches, do not interchange the BAU questions asked, as they mostly concluded on the CE approach as 'paying off' through reductions in climate impacts – however not necessarily discussing the temporal issues of the CE being implemented up front or prospectively, far out in the future. While the inherent issue of prospective assessments is obviously the uncertainty in modelling future scenarios, another central issue, not really discussed is the criticality of the issue solved by a given CE solution – i.e., some initiative may save up-front carbon emissions, whereas other enables future flexibility, e.g., through Design for Disassembly, and thereby supporting another forthcoming issue, resource scarcity.

From the review, it is concluded that the questions asked, and approach applied, does not differ significantly, when introducing CE into BE. While work is heavily ongoing in method development to accommodate some of the shortcomings experienced by assessors, this appears to be mostly based on BAU in the BE, as prescribed by the EN. Thus, it may be interpreted that the complexity is still not embraced, and thus other solutions, as known by the LCA community, are rarely considered.

3.P.03 Circularity Assessments in end-of-life of Photovoltaics Modules: Preliminary Results of Recycling and Reparation Processes

Daniel Garrain[1]*, Maria del Carmen Alonso-García*[1]*, Félix García-Rosillo*[1]*, María Beatriz Nieto*[1]*, Eduardo Mejuto*[1]*, Raquel Gómez-Rodríguez*[2]*, Roser Sala*[3] *and Miguel Ángel Muñoz-García*[4]*, (1)Energy, CIEMAT, Spain, (2)Ministerio para la Transición Ecológica y Reto Demográfico, Spain, (3)CISOT, CIEMAT, Spain, (4)ETSIAAB, LPF-TAGRALIA, Polytechnical University of Madrid, Spain*

Photovoltaic (PV) energy has been considerably growing for the past few years. There are currently more than 500 GW installed worldwide and it is estimated that power could reach 8,500 GW in 2050. Therefore, one of the consequences of this increase will be the high volume of generated waste in the coming decades. Estimations could reach 78 megatons in 2030-2035 worldwide. That is why FOTOVOL3R has emerged as a project, funded by the Spanish Ministry of Science and Innovation, whose main purpose is to provide solutions to the huge amount of PV module waste that will be generated once their end of life is reached. It addresses the concepts of Recycling, Repairing and Reusing (3R) together with the promotion of the circular economy to the whole life time of the PV modules.

This study presents an analysis of different methodologies in order to evaluate, analyze and quantify the concept of circularity, and their applications to several recycling and repairing scenarios of PV modules. Preliminary results show a clearly improvement of circularity values compared to those linearly, mainly when the main considered variable is the quantity of materials.

3.P.04 A Novel Approach to Estimate UK Household's Technology Metal Footprint

Xiaocheng Hu*, University of Exeter, United Kingdom*

Human activities have a significant impact on our environment. It is estimated that 27% of greenhouse gas emissions generated by human activities can be attributed to electrical and electronic equipment (EEE). Technology metals (TMs) are essential to the functionality of most EEE used in modern society. As demand continues to rise, mitigating supply risks is a top priority worldwide. Currently, household waste on EEE (WEEE) remain high and poorly managed. Many EEE are never repaired, nor the metals contained are recovered before ending up in the waste stream. This study developed a novel methodology to provide in-depth evidence on the annual estimates of EEE UK households purchased, wasted, and stocked, and the metals potentially contained for the period of 2011 to 2020. Market value and environmental impact of the TMs contained in household EEE are evaluated by linking our estimates with external LCI data. Results indicate that stocked EEE and WEEE are great sources to recover TMs. Precious metals, such as Au, has the most significant global warming impact. Measures, from both policymakers and industries, are urgently required to promote reuse, repair, and recycling within a sustainable circular economy model.

3.P.05 Life Cycle Assessment of Platinum Recycling from Used PEMFC Membrane Electrode Assembly

Mitja Mori[1]*, Rok Stropnik*[1]*, Jure Gramc*[1]*, Anna Marchisio*[2]*, Orhun Dedeci*[3]*, Christine Nayoze-Coynel*[4]*, Guillaume*

Braesch[4], Marie Heitzmann[4], Fabrice Micoud[4] and Andrej Lotric[1], (1)Department for energy engineering, University of Ljubljana, Faculty of Mechanical Engineering, Ljubljana, Slovenia, Slovenia, (2)Hensel Recycling, Aschaffenburg, Germany, Germany, (3)IDO-Lab, Karlstein, Germany, Germany, (4)Univ. Grenoble Alpes, CEA, LITEN, F-38054 Grenoble, France, France

Critical and rare earth materials are becoming more and more important not only from geostrategic and economical point of view, but also from environmental point of view. The focus of Europe in last years is to recover critical and rare earth materials from all possible technologies including fuel cell and hydrogen technologies, where platinum (Pt) as the main catalyst has the special position among PGMs. The work done in the scope of the EU Best4Hy project is (i) to create innovative life cycle inventories of existing End of life (EoL) (hydrometallurgical Pt recycling) and novel EoL (Pt and ionomer recycling) and (ii) to make life cycle assessment of closed and open loop recycling process. Membrane electrode assembly (MEA) of the proton exchange membrane fuel cell (PEMFC) is recycled using two approaches with multiple parameters adjustments and optimizations, to get Pt salt using hydrometallurgical process in the first stage of recycling and Pt/C catalyst powder in the final stage synthetized from polyol reduction synthesis using Pt salt. This Pt/C catalyst can be introduced again into a PEMFC MEA in a close loop. The inventory is set up in step-by-step approach for all processes included, so the LCA model can be easily adapted after scaling up from the laboratory scale. The functional unit used is the mass unit of Pt/C (catalyst powder with 3-4 nm Pt particles). Life cycle assessment methodology was used with environmental footprint 3.0 impact assessment methodology oriented in hydrogen relevant impact indicators as climate change, acidification, eutrophication, and resource use.

Available results of the Best4Hy Pt recycling are benchmarked with results from currently available Pt production (aggregated) processes from different databases/sources (Ecoinvent, GaBi) and/or from different industry sectors (Pt from automotive catalysts). With stepwise approach in the inventory and LCA model set-up, the environmental assessment of each step in the recycling process was made. The comparison of closed (within the same technology) and open (to other possible technology) loop recycling was done to demonstrate possible cross-sectional effects of Pt recycling.

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) under Grant Agreement No 101007216. This Joint Undertaking receives support from the European Union’s Horizon 2020 Research and Innovation program, Hydrogen Europe and Hydrogen Europe Research.

3.P.06 Environmental Life Cycle Assessment of Precision Agriculture Technologies – A Case Study of Crop Production in Austria

Francisco Medel*, Andreas Gronauer, Theresa Krexner and Iris Kral, University of Natural Resources and Life Sciences Vienna, Austria*

Precision agriculture technologies (PATs) aim to maximize resources and minimize environmental impacts by varying crop input rates based on crop requirements. Some of these technologies are proximal and remote sensors, automatic section control (ASC) and automatic steering for tractors. Several studies have shown the environmental benefits of these novel technologies however, a comparative life cycle analysis (LCA) study is inexistent. Moreover, few of the LCA studies focus mostly on variable rate input technologies. This research aimed to perform an LCA of employing PATs for crop production in an Austrian context. A crop rotation with five different crops was modelled. Preliminary results revealed that rapeseed was the most input intense crop showing higher outcomes in all of the evaluated environmental impacts. On the other hand, remote sensing using satellites images to produce nutritional maps for fertilizer application was the most effective technology showing the lowest results. For example, a 21% reduction in global warming potential (GWP) was achieved by implementing nutritional maps in comparison to conventional fertilizer application on rapeseed. PATs optimize crop inputs and bring positive environmental impacts, they help to tackle global warming and food scarcity.

4 Bioeconomy

4.01 Life Cycle Assessment of Methane Emissions from Disposal of Biodegradable Polyester in U.S. Landfills

Ketan Shah*, SCS Engineers®, United States of America*

Solid waste management (SWM) is an exigent and pressing problem for many cities. Globally landfills/open dumpsites are used to dispose of over 80% solid wastes, currently serving around 3.5-4 billion people. This number is expected to grow with increased urbanization and population growth (ISWA, 2015).

Methane generation, recovery, and emissions projections for biodegradable polyester fiber that will be used to create clothing products, which will eventually be disposed in municipal solid waste (MSW) landfills in the U.S. The scope of work described in this research project includes providing the methane estimates that discusses the data, assumptions, and calculation methods used to develop the estimates. Methane emissions estimates to help assess the potential impacts that producing new consumer products made with biodegradable polyester will have on greenhouse gas (GHG) emissions. As some U.S. states move towards requiring extended producer responsibility (EPR) for the packaging industry to address its waste management impacts, the analysis for the project commend firms for taking steps to pro-actively find a waste management solution for textiles, which may be the next target for Extended Producers Responsibility (EPR) legislation.

Objective 1 – Develop Estimates of Methane Generation from Disposed Polyester.
Objective 2 – Prepare Estimates of Methane Recovery Rates and Emissions Reduction from Utilization.
Objective 3 – Estimate Annual Net Methane Emissions for 100 Years.

The results are in the preliminary stage based on the assumptions for the methane generation potential and decay rates for the textiles. Indirect emissions reductions, avoided emissions from replacing the fossil fuel and utilizing the methane to generate electricity will be analyzed.
Thus, diverting waste going to the landfills helps in reducing the overall environmental impact by degradation of biodegradable polyester.

4.02 Towards the Development of an LCA Database on Circular Bioeconomy – as part of a toolbox supporting a stepwise approach for environmental impact assessment of regional circular bioeconomies

***Almut Güldemund**, TU Darmstadt, Germany*

Bioeconomy (BE) concepts aim to replace the current fossil based and linear economy in or-der to increase sustainability. However, the BE concept faces also criticism. The increased demand for biomass may lead to land use changes and intensification of agriculture and for-estry; both can contribute to environmental issues like global warming and biodiversity loss. Therefore, circular BE (CBE) concepts gain increasing attention in political strategies. An important element of CBE is the valorisation of by-products and wastes into high value products. However, the successful implementation of CBEs depends on regional conditions. Therefore, in order to support policy making, the evaluation of environmental impacts of CBE at the regional level is necessary.

We develop a stepwise approach together with a supportive toolbox that enable stakeholders to assess the environmental impacts of regional CBEs. The stepwise approach comprises the four steps: 1. Identification of region-specific conditions, 2. Selection of a set of CBE technolo-gies 3. LCAs of selected CBE technologies and 4. Extrapolation of LCA results to the regional level. The third step, in which the LCAs are conducted, is supported by an LCA database that comprises LCA datasets on different waste valorising biotechnologies. Currently LCA case studies on different CBE technologies are conducted covering technologies from the fields of e.g. insect farming, CO2 utilisation and chemical industry. These CBE technologies are devel-oped in research, development and innovation (RDI) projects as part of the innovation area BioBall in the metropolitan rhine-main-region in Germany.

Our results from several LCA case studies on CBE technologies show environmental impacts at lab and pilot scale. These are often high compared to conventional reference products, es-pecially the energy needs are dominating the impacts. Our upscaling scenarios also show that significant reduction potentials come with the implementation to an industrial scale. Next to our case study results we also show overarching conclusions about methodological challenges and potential solutions.

4.03 Comparative Screening Life Cycle Assessment of Various Recycling Technologies for Biocomposite Waste from the Aircraft Industry

***Spela Ferjan**, TNO, Utrecht, Netherlands*

The introduction of biocomposites in the aviation industry plays a crucial role in mitigating environmental impacts. These materials are partly or entirely derived from renewable resources. Therefore, they decrease the dependency on non-renewable fossil resources and potentially reduce greenhouse gas emissions (GHG) in the production stage. However, research on the end-of-life (EoL) processing of biocomposites is still in early stages. Investigating the EoL treatment options improves the circularity of the biocomposites, which contributes significantly to the sustainability along the life cycle of their application. This presentation shares the main insights of (EU-funded project) ELIOT, which focuses on assessing the feasibility and sustainability of the potential recycling technologies for biocomposite waste. The project has been conducted in three stages. Initially, a semi-quantitative multicriteria decision analysis (MCDA) was performed on 12 EoL treatment methods for six types of biocomposites. Next, the four technologies with the best score in the evaluation matrix were experimentally tested. The lab tests demonstrated that treatment of biocomposite waste through dissolution is not feasible. Finally, based on the best-performing experimental results, a screening Life cycle assessment (LCA) of three recycling methods was conducted on the biocomposite basalt fiber reinforced Polyfurfuryl Alcohol resin. In the LCA, 16 environmental impact categories are analyzed with ReCiPe 2016 Midpoint (H) impact assessment method. The functional unit is considered as 1 kg of biocomposite waste. Among the recycling technologies, pyrolysis shows the best GHG emissions performance (net emissions) with -0.802 kg of CO2-eq, followed by mechanical recycling with -0.777 kg of CO2–eq, and solvolysis with -0.644 kg of CO2-eq. The differences between the technologies are mainly related to the avoided burdens associated with the production of different virgin materials (aluminium hydroxide as a filler in mechanical recycling and basalt fibers in pyrolysis and solvolysis) and the energy intensity of the process steps. Even though the deviations in GHG emissions between the technologies are small, all alternatives perform better than the current practice of landfills (0.751 kg of CO2–eq). The LCA ranking of technologies has been compared with the MCDA ranking and the outcome of the comparison will be shared at the presentation.

4.04 Environmental Screening of Promising Carbon Capture and Utilization Routes in the Chemical Industry

***Ioan-Robert Istrate Sr** and Gonzalo Guillén-Gosálbez, Department of Chemistry and Applied Biosciences, ETH Zürich, Switzerland*

The utilization of CO2 as feedstock in chemical synthesis is recognized as a promising strategy to defossilize the chemical industry. While carbon capture and utilization (CCU) can contribute to mitigating climate change by replacing fossil feedstocks, the potential environmental benefits of the multitude of possible CO2-based reactions remain largely unexplored. In this work, we present a streamlined approach to identify CO2-based chemical reactions that could offer climate change mitigation potential while avoiding burden-shifting. We assessed 23 CO2-based reactions. For each reaction, we compute the ideal environmental performance for 1,092 CCU supply chains by combining three direct air capture options and 15 hydrogen sources deployed in 26 world regions. The ideal environmental performance equals the difference between the life cycle environmental impacts of reactants provision and substituted fossil route. The minimum amounts of reactants per kg of CO2-based chemical are based on the stoichiometric reaction, while the environmental impacts per kg of substituted fossil chemical are representative of current industrial practices. The most promising reactions are those with the highest number of CCU supply chains that could offer climate change mitigation potential while avoiding burden-shifting, considering the 16 impact categories available in the Environmental Footprint method v3.0. The analysis was performed under both a current energy scenario and a future scenario for the year 2050 that reflects deeper decarbonization of the economy. We found seven reactions (methane, methanol, acetaldehyde, ethane, ethanol, ethylene, acetone, and benzoic acid) for which all the CCU supply chains entail burden-shifting to other impact categories under both the current and prospective scenarios. Since the analysis is based on ideal conditions, the environmental performance of these reactions can only deteriorate. Based on our condition, the most promising chemicals are oxalic acid, methacrylic acid, and salicylic acid, for which more than 95% of the CCU supply chains could offer climate change mitigation potential without burden-shifting even today. Acetic acid (85-96% of CCU supply chains), propanol (65-66%), methyl formate (62-68%), and formic acid (61-65%) are also promising routes. The streamlined approach proposed in this work would allow concentrating efforts on those routes with the highest environmental potential.

4.05 Alternatives scenarios of the use of autumn tree leaves to supply energy and reduce greenhouse gas emissions – A case study from the city of Berlin

*Bianka Tscheuschner[1], Christiane Herrmann[2], Annette Prochnow[2], Ulrich Kreidenweis[2] and **Andrés de Jesús Vargas Soplin**[2], (1)Humboldt-Universität zu Berlin, Germany, (2) Leibniz-Institut für Agrartechnik und Bioökonomie e.V. (ATB), Germany*

Autumn tree leaves are residues that are generated annually and usually composted, but can also be used as a feedstock for biogas production. In this study, life cycle assessment (LCA) principles were adopted to establish three scenarios to evaluate the utilization of tree leaves from the city of Berlin in Germany: a) composting (business-as-usual scenario); b) biogas production; and c) the pretreatment of leaves before biogas production. For these scenarios, greenhouse gas emissions and energy production potential were calculated using the biological resource utilization impacts (BIORIM) model and considering the location and capacity of existing agricultural biogas plants. A special focus was set on the decay of leaves before their entry into the biogas plant. The overall comparison showed that the biogas-related scenarios had a better performance in terms of greenhouse gas emissions (-140.1 kg of CO2eq per tonne of leaves for biogas and -167.4 kg of CO2eq for pretreatment before biogas) than the business-as-usual scenario (49.0 kg of CO2eq for composting). The pretreated leaves resulted in the lowest net emissions and highest energy production per tonne of feedstock. Measures to reduce the decay of leaves, such as increasing the loading to the biogas plant or ensiling, resulted in lower net emissions and higher energy output. Net greenhouse gas emissions in the scenarios are sensitive to the type of leaves. Leaf types with lower dry matter content (i.e. lime tree leaves) resulted in lower organic carbon on a fresh matter basis, leading to lower biogenic emissions, while fossil emissions remained the same in all scenarios. Net emissions are also sensitive to the daily loads of tree leaves to the biogas plant in the biogas production scenario, such that lower loads led to more emissions from leaf decay, and less biomass available for energy production. Further research is needed regarding costs and logistical feasibility for proper implementation. Using tree leaves for biogas production would represent an alternative energy source, which could reduce the share of fossil fuels and electricity imports for the city of Berlin, where about 7.5 metric tonnes of pretreated leaves would meet the average electrical energy consumption of one person in one year.

4 Bioeconomy (Poster)

4.P.01 Future Environmental Impacts of Hardwood Lignin-based Adhesive in Comparison to Fossil-based One

***Anna Amanda Sander-Titgemeyer** and Gabriele Weber-Blaschke, Department of Wood Science, Technical University of Munich, Germany*

The current situation of using hardwood for energy production in Germany is conflicting with a bioeconomy strategy pushing towards material utilization of renewable resources. Products that enable a complete utilization of hardwood are being investigated. Due to the crookedness and branched growth of hardwood, large parts of the wood are not suitable for solid wood use. Instead, the use of wood components through the separation in biorefineries is rather promising. In particular, the utilization of wood lignin is being investigated to become both an economical and environmental-friendly resource. A promising example of the use of lignin is the substitution of phenol in adhesives. Phenol is so far based on fossil raw materials. The question arises whether a substitution by hardwood-based lignin leads to lower environmental impacts.

Today, there is no production of hardwood lignin-based adhesives. The environmental assessment of a future production on a mature production level require the up-scaling of foreground data as well as background data to a future point in time. Prospective attributional LCA is used inlcuding scenario development to investigate different production paths of lignin-based adhesives in comparison to conventional adhesive. The scope of the life cycle is chosen from resource extraction to manifacturing with a functional unit of 1 kg of adhesive (100 % solid content). For the bio-based adhesive product system, the extraction of the lignin can be done via three technology paths. The separated hardwood lignin can then be fragmented by three valorization processes. The production of an alike adhesive based on lignin can be achieved through three adhesive formulas.

Five selected scenarios for a future lignin-based adhesive production represent the future environmental impacts of the several production pathways. These scenarios are compared to the future prodcution of the conventionval adhesive assuming that the foreground production is continued as of today, but the background system is adapted to changing future conditions. The overall results show that the environmental impacts depend mainly on the choice of adhesive formula. The new developed adhesive cannot compete with a direct substitution of phenol by lignin from an environmental perspective. Substituting parts of phenol by lignin seems to be the better option for the future. However, the market shifts of increased lignin utilization have to be analysed by consequential LCA.

4.P.02 Potential environmental impacts for the production of medium-chain carboxylic acids from biological waste as an additional process step for existing biowaste treatment plants within the bioeconomy

***Patrick Christoph Brandes** and Iris Steinberg, Hochschule Darmstadt - Darmstadt University of Applied Sciences, Germany*

Compared to established treatment methods for biological waste (composting and fermentation) the production of medium-chain carboxylic acids from biological waste leads to the generation of higher-quality bio-based products. These are conventionally produced from petroleum-based raw materials or, in small quantities, from natural oils. By binding carbon atoms in the acids, carbon dioxide emissions can potentially be reduced during the degradation of the biomass. The objective of the study is to assess under which circumstances these positive effects outweigh the negative environmental impacts caused by the additionally required plant technology, energy or chemicals.

Whereby an extension of existing treatment plants for biological waste by this technology would lead to an overall optimized environmental performance. Furthermore, hot spots of negative environmental impacts are identified and recommendations for further process development are made.

To assess the environmental performance of the new technology a screening life cycle assessment is conducted with primary data generated by the research project "Combi4Produts" for the production of medium-chain carboxylic acids from biological waste and secondary data for background processes as well as the conventional production process. The secondary data is obtained from life cycle assessment databases combined with stoichiometric calculations, data based on literature and expert estimations verified by literature. For the calculation of environmental impacts various production scenarios are considered and modelled in the openLCA software. Subsequently environmental impacts from the new technology are compared to environmental impacts of conventional production processes for carboxylic acids. Possible rebound effects are also identified and discussed.

Results regarding potential hot spots have already been obtained and included in the research process. The energy consumption, extraction solvents as well as chemicals for pH-control have a high impact on the overall environmental performance of the new technology. Further research is currently being conducted to minimize or substitute these inputs. At the current state of the technology the new process leads to increased negative environmental impacts compared to the conventional production of carboxylic acids. To improve sustainability aspects of treatment plants for biological waste with the new technology, further process optimizations are required.

4.P.03 Optimization of the Environmental Performance of PHA Production Using Prospective LCA

Mateo Saavedra del Oso[1], *Miguel Mauricio-Iglesias*[1], *Almudena Hospido*[1] *and Bernhard Steubing*[2], *(1)Cross-disciplinary Research Center in Environmental Technologies (CRETUS), Department of Chemical Engineering, Universidade de Santiago de Compostela, Spain, (2)Institute of Environmental Sciences (CML), Department of Industrial Ecology, Universiteit Leiden, Netherlands*

Polyhydroxyalkanoates (PHA) production from waste streams using mixed microbial cultures (MMC) can unlock the potential of these biopolymers to substitute oil-based plastics. However, the development is still at low TRL (4-6). Prospective LCA can play a key role in the optimization of PHA production by MMC, upscaling these processes and ensuring that environmental guidance is included in the development. Thus, the aim of this work is to provide insights on the prospective optimization of the environmental performance.

Prospective LCA was combined with scenario methodology to envision how MMC PHA production could develop in the future (time horizon: 2030). The functional unit was defined as 1 kg of PHA. The system boundaries followed a cradle-to-gate approach, covering the PHA production (i.e., acidification, separation, biomass selection, PHA accumulation and downstream processing) and the further energy valorization of the residual streams. The scenarios were developed following a 4-step process: (1) identification of influencing parameters, (2) sub-scenarios for each parameter, (3) creation of scenarios from sub-scenarios and, (4) implementation of scenarios in the life cycle inventory model. Foreground and background scenarios were modeled using the superstructure approach as implemented in the Activity Browser. Uncertainty and global sensitivity analysis (GSA) was performed to evaluate the robustness of results.

Four scenarios were derived considering both background and foreground influencing parameters, such as environmental and bioeconomy policies, type of feedstock, acidification, and extraction yield. Results pointed out PHA downstream processing as the main hotspot within the process. When analyzing foreground parameters influence on environmental performance, feedstock and extraction yield are the key parameters. For instance, the latter is responsible for up to 60% of results variability. However, those processes with lower yield can mitigate partially the environmental impacts by employing the excess of heat produced in the valorization of intermediate residues. Regarding the influence of background parameters, ambitious environmental policies, which lead to lower carbon emissions in the electricity mix, can decrease the environmental impacts up to a 20%. As conclusion, this work elucidates how this technology could develop in the future and which parameters should stakeholders pay attention to.

4.P.04 Life Cycle Assessment of Palladium Recovery from Wastewater

Gema Amaya Santos[1], *Bert Lemmens*[2], *Kwinten van Eyck*[2], *Andrea Paulillo*[1] *and Paola Lettieri*[1], *(1)Chemical Engineering, University College London, United Kingdom, (2)Inopsys NV, Belgium*

Ensuring sustainable consumption and production patterns is one of the 17 UN goals for sustainable development. Reducing the negative impact of industrial activity through the efficient use of water, energy and raw materials is crucial to minimizing the impact on global climate change. In addition, it has become imperative to fully embrace the efficient use of resources, decoupling economic growth from environmental degradation, adopting a circular economy growth model. In this context, special focus is set on the recovery of scarce and valuable raw materials, developing new strategies to increase the effectiveness of their recovery towards the reduction of environmental impacts derived from extractive mining.

The present study depicts the environmental burdens derived from the recovery of palladium from an industrial wastewater effluent. In this work, the Life Cycle Assessment methodology is applied to quantify the environmental performance of a case study in Belgium of a commercial-scale palladium recovery process. The functional unit is the treatment of 100m3 of industrial wastewater effluent, for the removal of 90% of the concentration of Pd contained in the stream. The system boundaries comprise a cradle-to-gate study, in which a waste effluent from a previous industrial process is treated to extract valuable compounds from its matrix (i.e. Pd) that can later be used as raw material. The processes considered in the inventory of this study include the transport of materials and chemical products, and the disposal of derived waste in a waste-to-energy incineration facility with energy recovery. The mid-point environmental impacts of 9 different impact categories have been calculated using the E.F. 3.0 methodology. Results show that overall, recuperation of Pd from the wastewater effluent results beneficial towards minimizing the contribution to environmental burdens associated to avoiding the extraction and manufacture processes involved in the use of this precious metal as a primary feedstock.

4.P.05 Life Cycle Assessment of Bio-products from Post-extraction Rapeseed Meal Through Intermediate Pyrolysis

***Tahereh Soleymani Angili**, Katarzyna Grzesik, Wojciech Jerzak and Aneta Magdziarz, AGH University of Science and Technology, Kraków, Poland*

Recent interest in reducing stress on the environment, requires the use of renewable and organic resources for addressing ever-increasing sustainability concerns. Rapeseed meal (RM) is a by-product for the production of rapeseed oil, which is a potential feedstock to produce fuels and carbon-riched products via thermochemical conversion. The aim of the study was to investigate the early-stage Life Cycle Assessment (LCA) for post-extraction rapeseed conversion to biochar, bio-oil and syngas split over different scenarios. This study could be an approach to foresee the environmental hotspots in the very early development stage and for highlighting drawbacks connected to implementation of conversion processes at the pilot and industrial scale.

The goal of this study is to assess and compare the LCA result of rapeseed meal valorization scenarios. The scope of the LCA, covers intermediate pyrolysis process within a "gate-gate" system boundary where a chain of material/energy flow occurs to produce the final products. The scenarios differ in terms of catalyst usage and have modeled by SimaPro version 8.5.2.0 LCA software. The functional unit (FU) has defined as the conversion of 1 kg of biomass. The infrastructures of the equipment excluded from the system boundary, and the study focused on the operation of the system.

In this research, life cycle inventories (LCI) have prepared according to the optimized quantity of the materials, chemicals and energy utilized during the experiments and Ecoinvent database. The electricity consumption for the processes has calculated based on Poland`s national electricity grid. As per the LCI analysis of the RM conversion process to bio-products, the environmental impacts estimated by IMPACT 2002+ method. Then, the characterized impacts normalized so that the relative importance of the impacts in different categories considered in the LCA. The results demonstrate that this study is able to enhance sustainability aspects across intermediate pyrolysis process by (a) recycling rapeseed meal, (b) re-using the catalysts, (c) producing biochar that can improve organic cropping.

4.P.06 Applying Consequential Life Cycle Assessment to Evaluate Whether Bio-based Fertilizers Would Yield Environmental Benefits

***Lise Asscherichx**[1], Karolien Peeters[1], Cinta Cazador Ruiz[2], Javier Brañas Lasala[2], Esteban Serrano León[3], Victor Monsalvo Garcia[3], Marcia Barquero[4], Fernando González-Andres[4] and Katrien Boonen[1], (1)VITO, Belgium, (2)Fertiberia, Spain, (3) Aqualia, Spain, (4)University of León, Spain*

Multiple developments aimed at reducing the environmental impact of fertilizers are in the pipeline at research organizations and the fertilizer industry. Examples are the use of green hydrogen for ammonia production, use of by-products from other industries as raw materials or nutrients recovered from bio-waste and development of biostimulants. The research which will be presented in this poster focusses on the fertilizers developed in the B-FERST project and aims to assess whether using bio-based fertilizers would yield environmental benefits compared to conventional fertilizers. The bio-based inputs are struvite from Waste Water Treatment Plants (WWTP), ashes from WWTP (with and without available nutrients) and compost.

In LCA either the attributional or the consequential approach can be taken. To answer the research question, the consequential one has been found more adequate. It allows assessment of the expected changes when the newly developed fertilizers are applied instead of conventional fertilizers. Marginal technologies are used in the background system. The system boundaries (cradle-to-gate) include all changes that occur due to an action. Whether bio-based inputs are classified as waste or as by-products would be under discussion in attributional LCA. In consequential LCA this has no importance; the use of waste or by-products as raw materials implies that their former use or waste disposal is avoided. The functional unit is "the production of 1 tonne fertilizer with an NPK ratio of 10-10-10".

The results show carbon footprint reductions of bio-based fertilizers ranging from ca. 15% to 38%, depending on fertilizer type and bio-based material input. Fertilizers from ashes with unavailable nutrients show the smallest reduction due to an additional nutrient recovery step. In general, bio-based fertilizers bring environmental benefits for most of the 16 studied impact categories, but none of them yield a benefit in every category. In a second stage the use phase will be taken into account using results from field trials, which will deliver important additional insights. Availability and logistic aspects of bio-based inputs are investigated as well.

4.P.07 Consistent Methodological Framework for Including Biogenic Carbon Stock Changes in LCAs for Biomaterials

***Ilkka Leinonen**, Bioeconomy and Environment, Natural Resources Institute Finland (Luke), Finland*

The changes in biogenic carbon stocks are an essential component of climate warming, and these are strongly affected by changes in land use and management. Despite their importance, currently there are no generally accepted methods in LCA for handling the LULUC emissions and removals, i.e. the changes of biogenic carbon storage in biomass, dead organic matter and soil. As a result of this lack of consensus, biogenic products can be seen as a carbon source or sink, depending on the approach chosen. This situation is intolerable; without any common understanding of the environmental impacts of biobased production, it is very difficult for decision makers, companies, or consumers to make choices that would provide climate benefits. Therefore, this study presents a generally applicable, mass balance-based framework for including the biogenic carbon stock changes in LCA models in a consistent way, following the principles of international standards and guidelines. An important feature of the framework is to ensure that the rules of mass conservation are followed, making sure that that no omissions or double counting of carbon flows occur. The framework can be consistently applied for all biobased production, including both agricultural and forestry products. The method will also ensure that the changes in biogenic and fossil carbon storages are quantified in a consistent way, thus making it possible to assess the climate benefits achieved through replacement of fossil materials with biobased products. Examples of the application of the method are presented, showing how the method can be applied at different scales, i.e. national, landscape and forest stand levels. The examples especially demonstrate how the mass balance-based approach can avoid many unnecessary complexities associated with the LCAs currently applied for agricultural and forestry products.

4.P.08 Carbon Footprints of Alternatives Choices for PET Container and BO-PP Confection Wrapper

***Tarmo Räty**, Pooja Yadav and Ilkka Leinonen, Bioeconomy and Environment, Natural Resources Institute Finland (Luke), Finland*

Requirements for increased recycling of plastics and the need to develop ecologically sustainable replacement materials for fossil-based are recorded in the European Union (EU) Single Use Plastics (SUP) Directive. In this paper we have studied carbon footprints (CF) of alternative single-use plastic salad packaging solutions and individually packaged confection wrappers over their life cycles. The goal was to illustrate the impacts of material choices at gate and end of life (EoL) (recycling and incineration). Life cycle Inventories were based on ecoinvent v.3.7 and literature reviews; aiming to shed light on the relative contributions of impacts from materials and EoL treatments. All reference flows were adjusted to meet the same functional performance, meeting minimum mechanical requirements as well as quality and safety issues and labelling needs. Both fossil and biogenic carbon emissions were assessed separately. For salad packaging 8 biobased solutions with the same functionality as a 30 g polyethylene terephthalate (PET) container were identified and assessed. The highest impacts were found for PET, bioplastics and 27 g aluminum containers, where the CFs at gate varied between 102-118 g CO2 eq. For fiber-based containers the CF varied between 16-56 g CO2 eq. For confection wrappers, a Biaxially oriented polypropylene (BO-PP) wrapper (< 1g) and double layer wrappers of paper and aluminum, silicone, or Bio-PP (30%) had a CF about 2 g CO2 eq. at gate, clearly lower than any single layer biobased wrapper. However, if incinerated, the CF over the life cycle of PET or BO-PP clearly exceeded any of biobased solutions. Biogenic and fossil emissions of fiber-based solutions had always lower CF than the traditional solutions. For the fossil PET containers recycling reduced CF 35% or 65 % compared to incineration with current recycling rate 27.5% (Finland) and EU target 50% respectively. For the Bio-PP (30%), the relative gains were at the same magnitude. Energy credits accounted no more that 10-15% of the incineration CFs. Bio-based alternatives for fossil plastics had usually higher cradle-to-gate CFs but no EoL fossil CF if incinerated. Recycling reduces efficiently fossil EoL emissions for traditional plastics, but bio-based plastics only through replacing virgin materials. Fiber based solutions with lower at-gate CFs appeared more attractive choices for replacing traditional materials.

5 Transition Pathways

5.01 Exploring the Solutions to Decarbonize Warehousing Operations

***Sara Toniolo** and Ivan Russo, Department of Business Administration, University of Verona, Italy*

Every day goods are delivered to millions of consumers around the world and demand continues to grow. In line with the estimations of the International Transport Forum, freight emissions are expected to double by 2050. As revealed by the scientific literature, freight transportation and logistics sites generate an important contribution to CO2 emissions and when considering logistics activities for the development of decarbonization strategies, it is important to address not only transportation but also transshipment processes and warehousing.

The objective of this study is to explore what aspects of warehousing can contribute the most to the greenhouses emissions and what solutions can reduce the impact on climate change from a life cycle perspective. In line with the objective, this study addresses the following two questions: 1: What are the aspects of warehousing explored with a life cycle perspective? 2: What solutions may reduce the impacts associated with warehousing operations from a life cycle perspective? To answer these questions, a systematic literature review is conducted. A search by keywords is performed in ISI Web of Knowledge with a time horizon from 2000 to 2022. The keywords are selected and combined to investigate the papers whose contents deal with the focus of our study. The resulting combination of keywords is: (warehouse OR warehousing) AND ("life cycle assessment" OR "carbon footprint"). Only papers including consideration of warehousing processes and referring or applying environmental life cycle evaluations are included. Finally, 25 papers are selected for an in-depth examination.

A descriptive analysis is carried out to evaluate the main features of the articles; then the articles are classified considering the aspects analyzed and the possible solutions proposed to reduce the impact on climate change. This study highlights that the main aspects explored are energy consumption, infrastructure design, and materials handling and presents the solutions that can help directing towards the decarbonization of warehousing operations.

5.02 Model Recycling and Reuse as Joint Efforts when Possible

***Tomas Ekvall**[1] and Karin Sanne[2], (1)Division of Environmental Systems Analysis, Chalmers University of Technology, Sweden, (2)IVL Swedish Environmental Research Institute, Sweden*

Actors involved in circular solutions (source separating industries, second-hand dealers, users of recycled materials and reused components, etc.) sometimes ask for LCA results that quantify the environmental benefits of their activities. An LCA cannot readily do this because 1) it assigns burdens and benefits not to actors but to products, and 2) it entails a subjective choice among the dozens of methods available for modelling recycling and reuse.

However, the total net environmental benefits of the circular solution can be calculated and jointly assigned to all actors involved. In the case of material recycling you can state, for example: "Together you generate this environmental benefit, compared to a linear model where left-over material is discarded and only new material is used." Such a statement is more accurate than trying to allocate parts of the benefits to different actors. There is no need to subjectively choose a method to divide the environmental benefits of recycling between the life cycle generating the waste and the life cycle where the recovered material or energy is used. This solution is in line with the recommendation in the old SETAC "Code of Practice" to assess life cycles with recycling by studying the inputs and outputs from the total linked system. Last but not least, it sends the message that circular solutions are something we find and apply together.

Modelling open-loop recycling and reuse as joint efforts is not applicable when LCA results are needed for individual products, such as in an Environmental Product Declaration. However, it can be highly relevant, for example, to inform policymakers about the environmental benefits of a circular solution, to inform suppliers and customers of second-hand dealers about the benefits of reuse, etc.

5.03 Environment Spend Analysis – the methods producing the life cycle (LCA) data- and cost-based indicators that makes quantitative environment analysis of whole spend of purchasing possible

Jens Johansson[1] *and Tomas Rydberg*[2]*, (1)The National Agency for Public Procurement, 171 23 Solna, Sweden, (2)IVL Swedish Environmental Research Institute, Sweden*

What can make analysing large heterogenous volumes of purchasing possible? Life cycle (LCA) data is often based on weight (kg) or other physical units which causes problems for analysing purchasing, having often only monetary data available. The hypothesis was that developing methods to enable it, is possible. If so, Environment Spend Analysis (ESA) would be a method for organisations enabling them to analyse, quantitatively, the environmental aspects of whole volumes of purchasing and to prioritize efforts by addressing the purchasing categories that the ESA indicates has the largest environmental footprint. ESA integrates quantitative environmental indicators into the methods of spend analysis and category management. ESA integrates LCA and other environmental data into the field of purchasing. We developed the core of ESA to consists of indicators of environment aspects per spent monetary value (i.e. like CO2-equvivalents per Swedish krona). Each indicator is paired to a purchasing category. We based the environmental part of the indicators for goods on LCA data and for services data were also retrieved from other sources. Some products or service considered to have comparable footprints were assigned the same value. For Economic data we used statistics on import and export, categorised according to the Combined Nomenclature (CN). CN in many cases includes both economic data and other like weight (kg). The categories were matched to the CN. Data for services were retrieved from sources like environmental reporting. (Upphandlingsmyndigheten (Johansson J, Rydberg T, et. al. 2019) Miljöspendanalys - en metod för att analysera miljöpåverkan). In total, 491 purchasing categories has been populated with indicators. Examples are Gardening services 0,00523 CO2-e/kr, Road construction 0,00599 and Brochures 0,02879 etcetera. (Johansson, J. et al (2022-03-02) Miljöspendanalys, kategoriträd och miljöindikatorer process-LCA-metod. Upphandlingsmyndigheten, Solna.)

The indicators are applied to the methods of spend analysis, transforming spend analysis into ESA. A spend analysis is a generic tool for analysing an organization's total volume and different purchasing categories from an economic perspective (Pandit and Marmanis (2008) Spend Analysis – the window into strategic sourcing. J. Ross Publishing, Fort Lauderdale, USA).

This article describes and discusses the methods developed, sources of data used for producing the ESA-indicators and example on ESA in use.

5.04 Bottom-Up LCI Database of Chemicals and Plastics to Support Environmental Decision-Making

Oskar Vögler[1]*, Laura Stellner*[1]*, Arne Kätelhön*[1] *and Raoul Meys*[2]*, (1)Carbon Minds GmbH, Germany, (2)Carbon Minds GmbH, RWTH Aachen University Institute for Technical Thermodynamics, Germany*

As one of the largest contributors to global greenhouse gas emissions, the chemical industry faces the challenge of developing transition pathways to mitigate climate change. However, a large portion of emissions occur in the chemical supply chain. Life cycle assessment (LCA) is a powerful tool to consider all emissions from the entire value chain in transformation pathways and thus to evaluate climate change mitigation strategies from a holistic perspective. However, a large amount of data is needed to calculate LCAs, especially in a highly interconnected and globalized chemical industry.

To support global decision-making on climate change mitigation in the chemical industry, we have developed a novel life cycle inventory (LCI) database that complies with ISO standards for life cycle assessments (ISO 14040 and 14044). The database derives the data from a global higlhly regionalized model of the chemical industry. Therefore, we use a bottom-up approach, starting with the individual plants, combining geographic information with market, and technology-specific data. We then assign these individual plants to integrated production sites and national, technology-specific, and supplier-specific production mixes. Using trade data, we calculate regional and national consumption mixes from national production mixes. This approach allows to track emissions from chemical products and plastics along the global value chain and identify regional and even supplier-specific emission hotspots.

Our LCI database aims to assist LCA practitioners in conducting representative and reliable LCA studies for environmental decision-making using consistent LCI data on chemicals and plastics. Our database shows significant differences between regional production and consumption mixes that can be attributed to the different production technologies along the supply chain of chemical products and plastics. With our modelling approach, we are even able to show reduction potentials in supply chain emissions using supplier-specific data.

5.05 Life Cycle Assessment of Power Engineering Systems Considering Future Development

Vanessa Schindler[1]*, Sofia Haas*[2] *and Laura Göllner-Völker*[3]*, (1)Forschungsstelle für Energiewirtschaft e.V. / TU Darmstadt, Germany, (2)Forschungsstelle für Energiewirtschaft e.V., Germany, (3)IWAR, TU Darmstadt, Germany*

The energy sector is the biggest contributor to CO2 emissions and drives climate change. To comply with the goals of the Paris Agreement, this sector needs to decarbonize and negative emissions from carbon capture and storage are required. Thus, a rapid technological transition in the electricity sector is necessary. With the shift from fossil to renewable technologies, it is important to also consider indirect emissions of the future electricity system over the whole life cycle of the technology. Hence, Life Cycle Assessment (LCA) is used, as a is a powerful method to determine the environmental impact of products over the whole life cycle. Typically, LCA studies intend to support decision-making for a more sustainable world in the future. This contrasts with the fact that LCAs influence the future but are usually based on an ex-post view of the system. Typically, they collect data and assumptions from past processes and do not consider possible upcoming changes.

In this study, a methodological approach for conducting LCAs related to the electricity sector considering future development is presented. At first, general methods considering future aspects in LCA are collected and summarized. Then, the main environmental drivers influencing components of the electricity sector are evaluated. Additionally, possible future developments of power engineering systems are addressed. These main environmental drivers as well as the future development of the technologies are combined to give an overview of important results. To demonstrate the approach of this work, an exemplarily LCA of a battery system including future aspects is conducted.

This work contributes to the improvement of LCAs of the electricity system by incorporating future developments and serves as a practical guide for prospective LCAs of components of the energy system. It provides an overview of relevant future emissions of the electricity sector and is a fundamental step in quantifying them.

5 Transition Pathways (Poster)

5.P.01 Challenges of LCA to Provide Suitable Methods for Companies, and Understandable and Harmonised Results for Consumer Communication

Hannele Heusala[1]*, Juha-Matti Katajajuuri*[1]*, Terhi Latvala*[1]*, Sanna Hietala*[1]*, Ilkka Leinonen*[1]*, Frans Silvenius*[1]*, Katri Joensuu*[1]*, Karetta Timonen*[1]*, Kirsi Usva*[1]*, Kim Lindfors*[1] *and Hanna L. Tuomisto*[2]*, (1)Natural Resources Institute Finland (Luke), Helsinki, Finland, (2)Natural Resources Institute Finland (Luke), University of Helsinki, Helsinki Institute of Sustainability Science (HELSUS), Finland*

In transition towards a more sustainable future, companies are seeking for suitable assessment methods and consumers adequate information on sustainability consequences of their choices. LCA methods are constantly improving but are not yet harmonised. The use of the best scientific methods can be challenging for companies. Further, there are several challenges related to consumer communication: knowledge gaps regarding terms such as 'carbon footprint' and difficulties to understand where environmental impacts occur (Hartikainen et al. 2013, Camilleri et al. 2019). Most consumers are confused regarding which behavior changes are worth doing (Thøgersen 2021).

The aim of the project is to find most suitable assessment methods for harmonised LCA, as well as for climate communication. The proposed EC's Product Environmental Footprint (PEF) generic methods and agri-food product category rules (PEFCRs) and best available scientific models are critically assessed. Further, when necessary, suitable methods are identified for improving the production chains with more precise, nationally applicable models. The work is carried out by involving a large group of Finnish research organisations, agri-food companies from all parts of the supply chains, and other varied stakeholders.

The PEF process is likely challenged in finding adequate balance between the best scientific LCA methods for improving production chains, acceptance of industries and harmonised LCA methods for comparable results for communication. This can be seen in challenges to agree on allocation rules, as well as whether to provide fixed allocation factors, or allow specifications based on primary data. Moreover, different PEFCR do not aim to be harmonised and partially conflict with each other, which challenges application and communication. Yet, the PEF pilot phase has been able to identify the most critical environmental impacts of each studied product category, which can help to simplify communication and to make it more reliable. Specific local emissions models are reviewed whether they are aligned with PEF or contradictory.

LCA has been acknowledged to provide reliable information for improving supply chains and for consumers. But it does not always provide simple results that are easy to communicate. Sustainability labels are proliferating, but only a few are based on LCA. More reliable and simple enough assessment methods and information is needed for the sustainability transformation of our economy.

5.P.02 Global and Regional Sewage Management: Possible Trajectories for Multiple Environmental Impacts

Andrew Henderson*, Deborah Bartram and Sarah Cashman, ERG, United States of America*

The United Nations (UN) Sustainable Development Goal (SDG) 6 aims for adequate, equitable sanitation and hygiene by 2030. A range of sewage management approaches could achieve this goal; each approach has trade-offs related to public health, cost, and environment. This analysis evaluates the environmental implications of current and future sanitation management, given changes in sewage practices, energy supply, and population.

We considered present-day and future combinations of the following sewage management types:
* pit latrines (dry & wet; unlined & lined)
* septic systems
* container-based sanitation (CBS)
* sewers with no treatment
* sewers with primary or advanced (secondary or tertiary) wastewater treatment (WWT)

Our analysis used LCA to evaluate sewage collection, storage, transport, treatment, and emissions. Gathering information from UN, government, LCA databases, and literature, we used the highest resolution data available (e.g., ~1km for groundwater depth, country for future population scenarios), and we aggregate results based on UN Regions and World Bank income levels. We analyzed a suite of environmental impacts, including a metric for ocean acidification that was developed for this work.

Results indicate 60% of current global sewage GHG emissions and >95% of terrestrial acidification impacts are driven by latrine systems. Septic systems account for 25% of sewage GHG emissions. While primary WWT has low GHG emissions, these systems account for 74% of sewage eutrophication emissions. Because septic systems and primary WWT are defined as 'safe sanitation' in the SDGs, we show that current policy goals could have negative environmental effects.

Considering future scenarios, a mixture of CBS and advanced WWT appears to minimize impacts across most categories (e.g., global sewage GHG emissions in 2050 range from 54% to 110% of current emissions, depending on population). However, both CBS and advanced WWT have key areas that can be improved. For example, in areas with carbon-intensive electricity, the energy demands of advanced WWT lead to contributions to ocean acidification.

This analysis provides regional and global insight into environmental issues associated with sewage management. Where infrastructure is already 'locked in', we identify opportunities to reduce impacts. Where decisions will set future trajectories, this analysis informs policy decisions based on regional priorities.

5.P.03 System Comparison of Storable Energy Carriers from Renewable Energies - A LCA Construction Kit

Hans J Garvens, *German Environment Agency, Germany*

An essential prerequisite for a sustainable energy supply and greenhouse gas neutrality in Germany and worldwide is the complete conversion of the energy supply to renewable energies. However, these energy sources have a low energy density and are not uniformly available everywhere to the same extent. Therefore, a system is needed for the temporal and spatial connection between energy provision and use, which manages the provision of primary energy from the sun and wind, its conversion into storable energy carriers and their transport to the place of use.

In addition to the transition to climate and environmentally compatible energy sources and their efficient use, this connecting system must also have the lowest possible environmental effects. The underlying research project examines some 63 supply paths with the method of life cycle assessments and thus provides indications of which measures must be advanced in order to reduce the environmental effects of the supply, storage and transport of storable energy sources.

It remains essential to use energy as sparingly and efficiently as possible in order to reduce the required amount of storable energy sources from renewable energies and thus their environmental effects as much as possible.
To provide a bases of future work, in addition to the final report the data tables with the input data for the life cycle assessment calculation, its results and the results are also provided.

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