GCSM

21st Global Conference on Sustainable Manufacturing

Safe and Sustainable Value Creation by Design

September 10 to 12, 2025

Bologna, Italy

CONFERENCE BOOK

Last update: 11.09.25

» PREFACE

The University of Bologna, the Technical University of Berlin (IWF) and Fraunhofer IPK cordially invite you to the 21st Global Conference on Sustainable Manufacturing (GCSM) at the Faculty of Physics of the University of Bologna.

The GCSM serves as a global forum for academics, researchers, and specialists from universities, research institutes and industry across the globe, working on topics related to sustainable manufacturing. A unique feature of the GCSM conference series is its integration of industrial engineering perspectives, sustainable manufacturing applications in emerging and developing countries, as well as education and workforce development for advancing sustainable manufacturing. Plenary keynote speeches by experienced personalities from academics and industry, technical presentations in respective sessions and workshops of student teams from different countries offer new insights and chances for exchange of ideas. Session contents on product design, manufacturing processes and systems, and on crosscutting technological topics as education, business models, technology innovation are integrated under the umbrella of sustainability. Over 120 contributions will be presented in parallel sessions. They are authored and co-authored by personalities from more than 30 countries representing all continents of the globe.

Welcome to GCSM 2025 in Italy!
Best regards,

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(Local Chairman)

Prof. Dr.-Ing.
Franz Dietrich
(International Chairman)

Prof. Dr.-Ing.
Holger Kohl
(International Chairman)

Prof. Dr.-Ing.
Günther Seliger
(Founding Chairman)

2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
I. GCSM Alabama	II. GCSM Berlin	III. GCSM Shanghai	IV. GCSM Sao Carlos	V. GCSM Rochester	VI. GCSM Pusan	VII. GCSM Madras	VIII. GCSM Abu Dhabi	IX. GCSM St. Petersburg	X. GCSM Istanbul	XI. GCSM Berlin

2014	2015	2016	2017	2018	2019	2022	2023	2024	2025
XII. GCSM Johor Bahru	XIII. GCSM Ho-Chi-Minh-City	XIV. GCSM Stellenbosch	XV. GCSM Haifa	XVI. GCSM Kentucky	XVII. GCSM Shanghai	XVIII. GCSM Berlin	XIX. GCSM Buenos Aires	XX. GCSM Ho-Chi-Minh-City	XXI. GCSM Bologna

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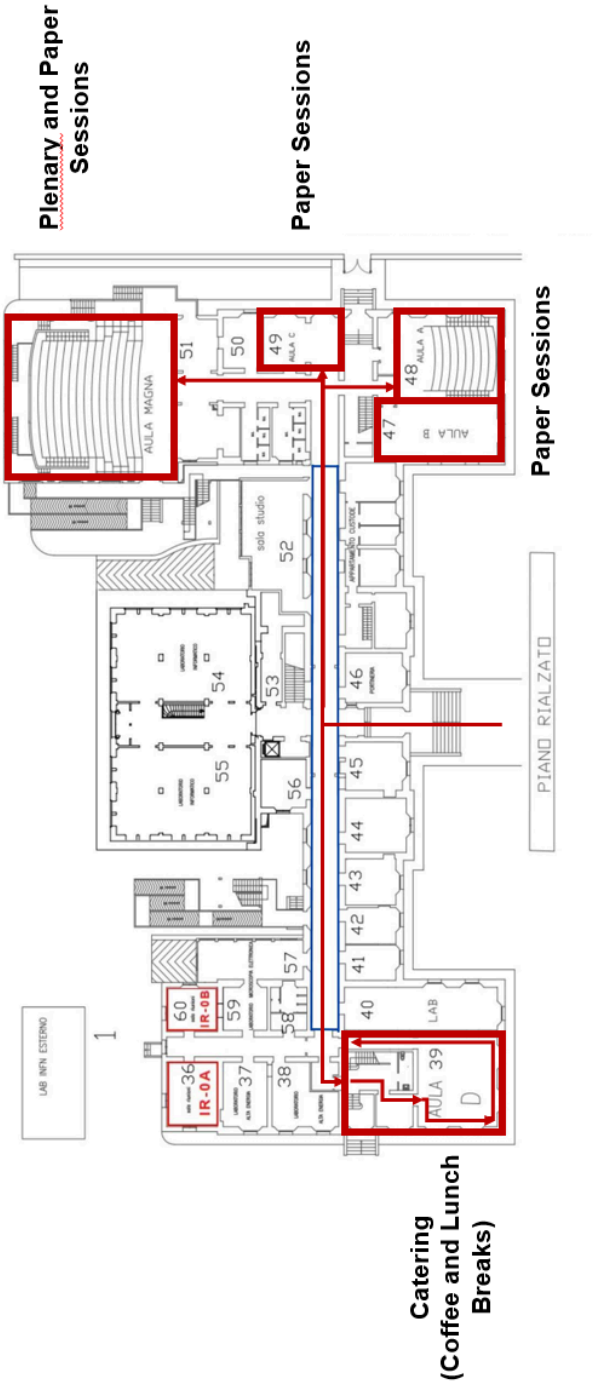
» CONFERENCE PROGRAMME

time\date	September 10, 2025			September 11, 2025				September 12, 2025		
08:30	Welcome and Registration			Reception				Reception		
09:00	**Conference Opening** UniBo's Dean and Conference Chairs			**Keynote Serenella Sala (Joint Research Centre)** Title: Safe and sustainable by design: evolving manufacturing and boosting competitiveness				**Keynote Speaker Michela Milano (UNIBO)** Title: Artificial Intelligence and Sustainability		
09:30	**Keynote Rainer Stetter (ITQ, Smart Green Island)** Title: Modern Education for a Sustainable Life			**Keynote Natascia Lai (HaDEA)** Title: Green and sustainable manufacturing: perspectives and success stories for European industries				**Keynote Fazleena Badurdeen (University of Kentucky)** Title: Sustainable Living Factories: A Product-Process-System Integrated Approach		
10:00	**Keynote Roberto Teti (University of Naples Federico II)** Title: Biologicalisation – The Biological Transformation in Manufacturing: A New Convergence Between Biology and Engineering			**Keynote Marie-Charlotte Montaut (IMA)** Title: Scaling Up Supply Chain Sustainability: A Data-Driven Approach to Regional Resilience **Keynote Mauro Ferri (SACMI)** Title: A History of Mutuality from Industrial Organisation and Products towards Sustainability				Coffee break		
10:30	Coffee break			Coffee break				**Session 22** Industry 5.0 Aula A	**Session 23** Corporate and Product Carbon Footprint Calculation Aula C	**Session 24** Supply Chain Aula B
11:00 11:30 12:00 12:30	**Session 1** Circular Economy Transformation Aula A	**Session 2** Additive Manufacturing I Aula Magna	**Session 3** Digitalization Aula B	**Session 10** Student session I Aula C	**Session 11** Design for Circularity Aula A	**Session 12** Artificial Intelligence Aula Magna	**Session 13** Factory Planning Aula B	Farewell and Outlook 2026		
13:00 13:30	Lunch break			Lunch break				Lunch break		
14:00 14:30 15:00 15:30	**Session 4** Circularity Evaluation Aula A	**Session 5** Additive Manufacturing II Aula Magna	**Session 6** Sustainable Corporate Transformation Aula B	**Session 14** Student session II Aula C	**Session 15** Sustainable Product Design Aula A	**Session 16** Safe and Sustainable by Design I Aula Magna	**Session 17** Factory Planning Aula B	Company visits (IMA, COESIA Group) / Museum visit UniBo		
16:00	Coffee break			Coffee break						
16:30 17:00 17:30 18:00	**Session 7** Value Retention Processes Aula A	**Session 8** Manufacturing Processes Aula Magna	**Session 9** Green Energy Systems Aula B	**Session 18** Education and Training Aula C	**Session 19** Assessment of Sustainable Products Aula A	**Session 20** Safe and Sustainable by Design II Aula Magna	**Session 21** Production Planning and Control II Aula B			
18:30				Bus transfer to Conference Dinner						
19:00				Conference Dinner						

» MAP OF THE VENUE



» KEYNOTE LECTURES

Keynote 1:

Wednesday, September 10th, 09:30 – 10:00 a.m.

Dr.-Ing. Rainer Stetter - GCSM 2025 Keynote speaker

Title: Modern Education for a Sustainable Life

Chief Executive Officer, ITQ GmbH Founder, Smart Green Island Makeathon

Abstract:

Technological sovereignty, sustainability and digitalisation – Europe faces major challenges. Dr Rainer Stetter, CEO of ITQ GmbH, pursues a clear vision with his educational approach: to inspire young people to take an interest in technology at an early age, promote practical skills and enable them to play an active role in shaping a sustainable future.

At the heart of this strategy is a cross-generational, scalable educational approach that combines theory with practice and education with industry. The SMART GREEN ISLAND MAKEATHON serves as a blueprint for this: interdisciplinary teams of students develop innovative prototypes there in a very short time – a model that can be adapted across Europe. And it has already found many imitators.

This format is supplemented by STEM workshops and the EU-funded EduDemoS project, which brings technological demonstrators – for example, on robotics, recycling or renewable energies – to schools. Students act as coaches for children and young people, which has both an educational impact and a multiplier effect.

This systemic approach provides direct access to talent, promotes relevant future skills and makes a concrete contribution to solving the shortage of skilled workers in Europe.

Conclusion for decision-makers:
Those who view education as a strategic tool will recognise this as an effective model – scalable, practical and ready for transfer to business, schools and society.

Keynote 2:

Wednesday, September 10th, 10:00 – 10:30 a.m.

Prof. Roberto Teti - GCSM 2025 Keynote speaker

Title: Biologicalisation – The Biological Transformation in Manufacturing: A New Convergence Between Biology and Engineering

Director of the Fraunhofer Joint Laboratory of Excellence on Advanced Production Technology (Fh J_UniNaples), University of Naples Federico II

Abstract:

The Biological Transformation, or Biologicalisation, in Manufacturing has been defined as a ground-breaking frontier that industry can harness to improve circularity and sustainability while increasing production efficiency and competitiveness through technological advances arising from the integration of bio-intelligent principles, functions, structures, materials and technologies in manufacturing engineering by applying knowledge derived from biology. To achieve such accomplishments, a convergence of biology and biotechnology, manufacturing processes and systems, information technology and ICT systems is essential for a breakthrough innovation change.

The first part of the keynote presentation reports on an ambitious international study carried out on the topic of the convergence between biology (the biosphere) and manufacturing engineering (the technosphere). Four demonstrators from different sectors of the manufacturing value chain and involving bio-inspiration, bio-integration and bio-intelligence were selected to test the focal hypothesis that: “Future Manufacturing Systems will incorporate Components, Features, Characteristics and Capabilities that enable the convergence towards Living Systems”.

The second part of the presentation relates to first EU call topic on Biologicalisation, titled “Development of technologies and devices for bio-intelligent manufacturing”, published in 2022 within the Horizon Europe Programme. In response to this call, the project “A Modular Framework for Designing and Producing Bio-Hybrid Machines (BHM) – BioMeld“ was successfully submitted and approved with duration 2023-2026. The ‘BioMeld’ project achievements are illustrated with regards to the integration of biological and artificial materials to achieve greater autonomy, flexibility and energy efficiency in the realisation of a BHM consisting of a bio-hybrid vascular catheter as innovative medical device for improved drug delivery in hard-to-reach areas of the human body.

Keynote 3:

Thursday, September 11th, 09:00 – 09:30 a.m.

Dr. Serenella Sala - GCSM 2025 Keynote speaker

Title: Safe and sustainable by design: evolving manufacturing and boosting competitiveness

Head of the Land Resources and Supply Chain Assessment Unit of Directorate D - Sustainable Resources at the Joint Research Centre (JRC)

Abstract:

The European Commission framework on "Safe and Sustainable by Design (SSbD) of chemicals and materials" is aiming at steering innovation by integrating considerations on safety, environmental and socio-economic sustainability as well as circularity and strategic autonomy. A lifecycle perspective underpins the SSBD framework, minimising safety concerns and environmental impacts from raw material extraction to end-of-life. This approach addresses global challenges like resource scarcity, climate change and other environmental impacts, and public health and environmental risks while aligning competitiveness with green transitions.

In relation to resource scarcity, Critical Raw Materials (CRMs), such as rare earth metals and lithium, pose significant risks due to geopolitical concentration and finite availability. Sustainable design mitigates these challenges by substituting CRMs, optimising material use, and using advanced materials. Indeed, innovation in advanced materials further propels sustainable manufacturing.

The European Commission Raw Materials Information System aims at informing on this interplay between raw materials and strategic technologies, including addressing geopolitical concerns, environmental and social impacts, as well as the potential of advanced materials to replace CRMs. Transitioning to these practices requires overcoming barriers, including high upfront R&D costs and fragmented supply chains. Collaboration between policymakers, industry, and academia, through subsidies, standardisation, and public-private partnerships, is vital to accelerate adoption.

As global markets prioritise decarbonization and resource resilience, manufacturers that embed sustainability into design will lead in innovation and market relevance. By redefining product lifecycles and material use, industries can drive systemic change, ensuring growth aligns with planetary boundaries. This holistic approach positions "safe and sustainable by design" as a cornerstone of a future where manufacturing thrives while considering safety and sustainability dimensions.

Keynote 4:

Wednesday, September 10th, 09:30 – 09:50 a.m.

Natascia Lai - GCSM 2025 Keynote speaker

Title: Green and sustainable manufacturing: perspectives and success stories for European industries

Deputy Head of Unit B3 – Industry, Health and Digital Executive Agency (HaDEA)

Abstract:

The speech explores how green and sustainable manufacturing is becoming central to the future of European industry and how Horizon Europe can help to make it happen. Aimed at potential project participants, it presents the Factories of the Future (FoF, H2020) and Made in Europe (MiE, Horizon Europe) partnerships, previous call topics, relevant and successful projects, lessons learned and how the funded projects innovate. Key themes are the circular economy, energy and resource efficiency, zero-defect manufacturing, data collection and processing, including ML/AI, cloud/edge/IoT technology and digital innovation for sustainability.

The talk will also explore how initiatives such as the New European Bauhaus (NEB), the Digital Product Passport (DPP), and Safe and Sustainable by Design (SSbD) are leading the way in integrating sustainability into manufacturing processes. Upcoming funding opportunities within Cluster 4 (Digital, Industry and Space) for 2025 and 2026-27 are mentioned too. Attendees will also gain a clearer view of where the opportunities lie and how the EU-funded projects contribute to the Green Deal.

Keynote 5:

Thursday, September 11th, 09:50 – 10:10 a.m.

Marie-Charlotte Montaut – GCSM 2025 Keynote Speaker

Title: Scaling Up Supply Chain Sustainability: A Data-Driven Approach to Regional Resilience

Sustainability Office, IMA Group

Abstract:

Climate change and environmental pressures are increasingly redefining industrial competitiveness. Manufacturing companies are beginning to recognise that their supply chains are not only crucial for production continuity but also key to driving sustainability and resilience across regions. For IMA Group, a global leader in the design and manufacture of automatic machines for processing and packaging, this has meant building strong, long-term collaborations with suppliers, particularly the small and medium enterprises that form the backbone of regional manufacturing ecosystems.

In 2023, IMA launched a structured ESG programme to support its suppliers in addressing these challenges. A first wave of strategic partners was engaged through a combination of dialogue, ESG data collection, targeted development pathways, and shared improvement plans. The programme already reflects a growing momentum within the supply network: many suppliers are now taking concrete steps, such as measuring emissions and setting climate targets, while challenges remain in areas such as governance, risk management, and circular economy integration.

This keynote will explore how a large industrial player can activate and support its supply network to accelerate climate adaptation and decarbonisation, while mitigating the risk of uneven progress or compliance-driven burden shifting. It will also reflect on how to translate global sustainability frameworks into actionable, regionally integrated strategies that strengthen not just the company but the wider industrial ecosystem.

Keynote 6:

Thursday, September 11th, 10:10 – 10:30 a.m.

Mauro Ferri - GCSM 2025 Keynote speaker

Title: A History of Mutuality from Industrial Organisation and Products towards Sustainability

Corporate Quality Control Director of the Corporate Supply Division, SACMI Group

Abstract:

Founded as a cooperative, SACMI is rooted in a long-standing mutualistic tradition that has shaped its industrial development. Integrating mutual principles into products and processes now represents a strategic opportunity to strengthen its commitment to sustainability. Initial steps in this direction are reflected in the development of preliminary studies and the drafting of the first sustainability report, marking the beginning of a structured and transparent journey.
The speech will deal with the following topics:

The evolution of SACMI's cooperative identity: from mutual aid among workers to a driver of innovation and global competitiveness.

Organisational transformation: how mutuality influenced governance, long-term strategy, and the resilience of the enterprise model.

Industrial innovation: embedding mutualistic principles in the design of technologies and industrial solutions for key sectors (ceramics, packaging, food).

Towards sustainability: aligning mutual values with environmental and social responsibility in both internal practices and value chain impacts.

The first sustainability report: methodologies, challenges, and insights gained from SACMI's debut in sustainability reporting.

Next steps: integrating ESG frameworks, circular economy approaches, and cooperative governance in a long-term sustainability strategy.

Keynote 7:

Friday, September 12th, 09:00 – 9:30 a.m.

Prof. Michela Milano - GCSM 2025 Keynote speaker

Title: Artificial Intelligence and Sustainability

Head of Alma AI (Alma Mater Research Institute for Human-Centred Artificial Intelligence), Department of Computer Science and Engineering (DISI), University of Bologna

Abstract:

tbd

Keynote 8:

Friday, September 12th, 09:30 – 10:00 a.m.

Prof. Fazleena Badurdeen - GCSM 2025 Keynote speaker

Title: Sustainable Living Factories: A Product-Process-System Integrated Approach

Professor of the Institute for Sustainable Manufacturing, Department of Mechanical Engineering, University of Kentucky

Abstract:

Sustainable manufacturing is no longer a choice—it is a necessity for ensuring long-term economic viability, environmental stewardship, and social well-being. Achieving this vision demands more than incremental improvements; it calls for a systemic transformation of how products are designed, how they are manufactured, and how value chains operate. This transformation must be grounded in a holistic understanding of the interdependencies among the three core domains of manufacturing: products, processes, and systems. Decisions in product design directly influence manufacturing processes and supply chain configurations, just as process innovations and systemic changes reshape what products can be manufactured to promote sustainable value creation. However, traditional approaches often treat these domains in isolation, leading to fragmented efforts and suboptimal outcomes. This presentation will examine the need for emerging and integrative approaches that bridge these silos—strategies that align to promote innovations across the product-process-system nexus—to drive meaningful and measurable progress toward truly sustainable manufacturing. Transformative research and education practices that prioritize coordinated action across domains for greater benefits to pave the way for a next generation sustainable manufacturing for sustainable value creation will also be examined.

» PAPER SESSIONS

Wednesday, 10th September - 11:00 - 13:00		
Paper Session 1 **Circular Economy Transformation**	**Paper Session 2** **Additive Manufacturing I**	**Paper Session 3** **Digitalization**
Prototyping Circular Business Model Innovation: An Approach for Addressing Systemic Complexity (ID 22)	Enhancing Sustainability in Polymer Additive Manufacturing by Simulations through Computational Fluid Dynamics (ID 129)	Case Study Analyses of Benefits and Barriers of Circular Manufacturing Systems: A Step Towards a Simulation-Based Approach (ID 37)
Circular economy transformation through pattern recognition (ID 94)	Enhancing Sustainability in SLS: Reliable and Practical Methods for Assessing Powder Aging (ID 29)	Digitization in Serial Timber Construction Manufacturing: A Model-Based Approach for Sustainable and Efficient Production (ID 182)
Tools and Methods Supporting SMEs in Implementing Circular Practices (ID 53)	Sustainability of Polylactic Acid Fibre Composite for Additive Manufacturing (ID 11)	Digitalizing Circular Construction: Operationalizing Circularity Metrics through BIM and BI–Integrated Workflows in Timber Prefabrication (ID 195)
Berlin's Transition to an Industrial Circular Economy: Analyzing the Competences of Manufacturing SMEs (150)	Circular Use of Polyamide 12 in Additive Manufacturing (ID 57)	Utilizing manufacturing digital twins for sustainability reporting (ID 151)
Realizing Circularity in Manufacturing as a Service Systems: An Indicator Screening Tool for Product Level Circularity Indicators (ID 34)	A Study on the Effects of Fibre Orientation and Layer Stacking Sequence on Mechanical and Energy Performance of CFRCs (ID 179)	Exploring the Role of DPPs in Smart Circular Economy: a conceptual Synthesis (ID 194)
	Evaluation of the potential of Large-Scale 3D Printing to promote a circular economy of PET Plastic Bottles: comparison between European and North American Context (ID 115)	

Paper Session 1: Circular Economy Transformation
Wed, 10th September - 11:00 - 13:00

Aula A

Prototyping Circular Business Model Innovation: An Approach for Addressing Systemic Complexity (ID 22)

Marcel Fischer (PTW - TU Darmstadt)*

Abstract. The transition to a circular economy is considered a promising approach to promoting sustainable economic practices. Due to the complex inter-dependencies between product characteristics, value creation architecture, and benefit distribution, companies often struggle to effectively adapt their existing business models. In this context, business model innovation can serve as a cata-lyst for the implementation of circular economy principles. However, existing approaches and tools for business model innovation often fail to adequately ad-dress the systemic perspective and its inherent complexities within the circular economy. In response, this paper presents a framework for prototyping circular business models that aligns with systemic perspective by incorporating addi-tional informational needs throughout the product lifecycle. This facilitates a comprehensive representation of the associated circular system by accounting for all interrelated stakeholders and their specific characteristics. As a result, the framework enables the systematic identification of potential opportunities and conflicts within prototypical circular business models, thereby strengthening the foundation for their successful implementation. Finally, the approach is validat-ed through a case study in the context of the manufacturing industry.

Keywords: Circular Economy, Business Model Innovation, Prototyping

Circular economy transformation through pattern recognition (ID 94)

Barna Gal (Fraunhofer Austria Research GmbH)*; Theresa Madreiter (Fraunhofer Austria Research GmbH); Henry Nicolai Buxmann (Fraunhofer-Institut für Produktionsanlagen und Konstruktionstechnik IPK); Benjamin Gellert (Fraunhofer-Institut für Produktionsanlagen und Konstruktionstechnik IPK); Sebastian Schlund (Technische Universität Wien)

Abstract. As part of the European Green Deal and the resulting requirements of the Corporate Sustainability Reporting Directive (CSRD), there is increasing pressure on (manufacturing) companies to strategically integrate sustainability into their business model and subsequently reduce emissions. One key to greater sustainability is the transition from a linear to a circular economy. Although the integration of circular economy principles at business model level is widely discussed in the literature, companies often lack relevant information on which of these models and strategies are best suited to them. This information includes data-based and quantifiable statements about the effects on the business model and corporate performance. The overarching aim of this paper is to highlight a developed framework to enable companies to select the most suitable, effective and economical circular economy business model (CEMBM) by means of a decision support system (DSS). To this end, the system analyzes company-specific data and suggests suitable business model patterns. In addition, the system will provide an initial quantitative assessment of the potential impact of the proposed business model patterns on the business model. By taking suitable economic and ecological metrics into account, companies will receive a sound basis for making decisions on how to expand their own circular economy performance.

Keywords: Circular Economy, Knowledge Graphs, Business Model Canvas

Tools and Methods Supporting SMEs in Implementing Circular Practices
(ID 53)

Jessica Fink (Institute of Recycling, Ostfalia University of Applied Sciences)*; Thomas Potempa (Institute of Recycling, Ostfalia University of Applied Sciences); Max Juraschek (Institute of Recycling, Ostfalia University of Applied Sciences); Klaus Bolze (Institute of Recycling, Ostfalia University of Applied Sciences); Suharshi De Silva (Department of Mechanical and Industrial Engineering, Atlantic Technological University); Deborah Huber (Institute of Psychology, University of Graz); Albert Dietrich (Institute of Psychology, University of Graz); Erich Wechselgartner (Institute of Psychology, University of Graz); Aurora Dimache (Department of Mechanical and Industrial Engineering, Atlantic Technological University); David Gorman (Department of Mechanical and Industrial Engineering, Atlantic Technological University); Max Ehleben (Institute of Recycling, Ostfalia University of Applied Sciences)

Abstract. With 25.8 million small and medium-sized enterprises (SMEs) in the EU, SMEs represent an essential role in the European economy, thus having a significant cumulative impact on the environment. One measure to reduce these environmental impacts is the implementation of circular practices, enabling waste prevention and resource efficiency. To support enterprises moving from linear to circular practices, numerous methods and tools have been developed. However, while these tools can offer substantial benefits to enterprises, there is a need to explore whether they are tailored to the specific needs of SMEs that may face cost or time constraints. This study addresses this gap by systematically reviewing and evaluating currently available circular economy tools, focusing on online visibility and ease of access for SMEs. The findings reveal access barriers, such as mandatory registration and difficulty discovering suitable tools, along with a clear lack of SMEspecific solutions. These insights offer practical value for both researchers and SMEs seeking more targeted sustainability solutions.

Keywords: Circular economy, Circular design, Tool review, Small and medium-sized enterprises, SME.

Berlin's Transition to an Industrial Circular Economy: Analyzing the Competences of Manufacturing SMEs
(150)

Felix von Amelunxen (Technische Universität Berlin)*

Abstract. The city of Berlin has set ambitious goals to become a leading circular economy (CE) city, implementing various strategies to drive this transformation. However, the successful transition to a CE critically depends on the ability of businesses to realign operations, infrastructures, and supply chains with circular principles. Small and medium-sized enterprises (SMEs) in the manufacturing sector face distinct challenges in this process and require targeted, context-specific support. This study investigates the CE awareness and competence needs of Berlin's manufacturing SMEs through an explorative, qualitative survey among industry representatives. The findings reveal significant knowledge gaps, particularly regarding advanced CE strategies and emerging regulatory frameworks. Furthermore, they give insights into preferred competence building elements. The results directly inform the development of a Berlin-based digital competence platform designed to provide SMEs with tailored capacity-building measures, thereby supporting their effective engagement in the circular transition.

Keywords: Circular Economy, Transition, Competence Building

Realizing Circularity in Manufacturing as a Service Systems: An Indicator Screening Tool for Product Level Circularity Indicators
(ID 34)

Amira Bushagour (Aarhus University); Magnus Siim Jensen (Aarhus University); Rami Mansour (Aarhus University); Devarajan Ramanujan (Technical University of Denmark)*

Abstract: It is becoming clear that a paradigm shift away from linear economies to circular economies is necessary to reduce our environmental impact and slow our use of non-renewable resources. Manufacturing as a service has been proposed as an avenue towards realizing circular economy through its unique characteristics and data handling abilities. Industry is one of the driving actors in this shift to a circular economy, but without proper tools it is difficult for a company to benchmark their progress reliably. Indicators to benchmark this progress are plentiful, especially with the addition of the new ISO standards regarding circular economy in May of 2024. However, the data burdens required for manufacturers to benchmark circularity can be vast and unclear. This paper both investigates manufacturing as a service's role in the transition towards a circular economy and presents a circularity indicator screening tool for manufacturers, to aid decision makers in choosing indicators that align with circularity goals and data availability. This tool breaks down the data burdens for product-level circularity indicators with the addition of the ISO circular economy indicators, providing the user with circularity indicators that match their needs, while simultaneously categorizing these indicators following the ISO guidelines on circular economy.

Keywords: Circular Economy, Manufacturing As A Service, Circularity Indicator, Data Burdens

Paper Session 2: Additive Manufacturing I
Wed, 10th September - 11:00 - 13:00

Aula Magna

Enhancing Sustainability in Polymer Additive Manufacturing by Simulations through Computational Fluid Dynamics (ID 129)

Rita Porcaro (University of Bologna)*; Giampaolo Campana (University of Bologna); Amy Peterson (University of Massachusetts Lowell); Maurizio Fiorini (University of Bologna)

Abstract. This research examines the benefits of utilizing Computational Fluid Dynamics (CFD) simulations to enhance the sustainability of the Arburg Plastic Freeforming (APF) additive manufacturing process, focusing on polycarbonate as the primary material. Simulating polycarbonate's behavior during extrusion from a heated nozzle into a heat-controlled chamber, this study aims to understand thermal dynamics and material flow to optimize manufacturing. Implementing manufacturing process simulations through CFD presents a significant opportunity to make tailored adjustments to processing parameters, considerably reducing material waste and energy consumption. This capability allows manufacturers to identify efficient workflows and minimize resource use before physical trials, addressing sustainability challenges in the sector. Moreover, the insights derived from these simulations can enhance product quality and durability, reducing the necessity for frequent replacements and supporting overarching sustainability objectives. By illustrating the efficacy of simulation technologies in optimizing the APF process, this research highlights the transformative potential of advanced modeling techniques in driving innovation and promoting sustainable practices in the polymer industry. Ultimately, this study highlights the indispensable role of CFD simulations in facilitating the transition toward more sustainable production methodologies. This work addresses environmental challenges and highlights the importance of strategic simulation practices for achieving sustainability in additive manufacturing and beyond.

Keywords: Additive Manufacturing; Computational Fluid Dynamics (CFD); Digital Twin Model; Industry 4.0.

Enhancing Sustainability in SLS: Reliable and Practical Methods for Assessing Powder Aging (ID 29)

Piia Kanto , Simo Huhtanen and Katri Salminen
Tampere University of Applied Sciences, 33520 Tampere, Finland

Abstract. Selective laser sintering (SLS) is an additive manufacturing technology with great potential for producing 3D components, particularly those with complex geometries and customized designs. In SLS printing, only a small amount of the powder is sintered into parts during each build, while the rest remains unused but preheated. Discarding this un-sintered material is both costly and wasteful. Reusing polymer powder helps reduce material costs and enhances the sustainability of the process. However, powder reuse affects the polymer, impacting its processability and the quality of printed products. Previous studies have shown that excessive reuse of powder significantly alters e.g. mechanical properties, and visual appearance of printed parts as well as the flowability of polymer powder during printing. There is still a lack of practical methods to easily determine under real process conditions when a powder has aged beyond usability. In this study, we aim to improve raw material efficiency, reduce waste, and enhance material recycling by evaluating analytical techniques using real process samples of PA12. Our goal is to examine real powder samples obtained from the SLS process and provide companies with information on the effectiveness of different analysis methods in obtaining reliable data on material aging and reusability.

Keywords: SLS printing, powder aging, PA12, MFR, DSC, melting point

Sustainability of Polylactic Acid Fibre Composite for Additive Manufacturing
(ID 11)

Ezutah Olugu (University of Witwatersrand); Uzoma Okoro (University of Witwatersrand)*

Abstract. Polylactic acid (PLA) composites of natural and synthetic fibres possess the requisite attributes of environmentally friendliness and superior mechanical properties, which qualify them as a potential replacement for fossil-fuel-based polymer filaments in Fused Deposition Modelling (FDM). However, Life Cycle Analysis is required to establish their sustainability and support their full industrial application. This research investigates the functional performance and sustainability of natural and synthetic PLA composites to evaluate their suitability for varied industrial applications. Samples of PLA-wood and PLA-glass fibre composite were formed, and the tensile strength, compressive strength, and moisture absorption properties were tested and compared to those of a pure PLA specimen. Furthermore, the sustainability of the composites was analysed based on the triple bottom line and life cycle analysis-considering the material extraction, manufacturing, distribution, usage, and end-of-life. The research concludes that glass-fibre PLA ranks as the most sustainable alternative in situations where the mechanical properties of conventional PLA are insufficient for the intended application. However, glass-fibre PLA is not a sustainable alternative where polylactic acid cannot be utilised otherwise. Wood-fibre PLA has social and economic sustainability drawbacks, which limit its suitability as a sustainable alternative to conventional PLA; therefore, it is not a sustainable alternative in most AM applications.

Circular Use of Polyamide 12 in Additive Manufacturing
(ID 57)

James Call (Loughborough University)*; Shahin Rahimifard (Loughborough University)

Abstract. The application of additive manufacturing (AM) technologies is rapidly expanding within various manufacturing sectors, highlighting an urgent need to consider the Circular Economy of parts produced using these technologies. This involves the reprocessing of end-of-life (EoL) products made of a variety of materials using a wide range of AM processes to divert waste from conversion to energy or landfilling. This research explores various options for the EoL processing of parts produced through Selective Absorption Fusion (SAF), with a particular focus on polyamide 12 (PA12). SAF is a new additive manufacturing process developed by Stratasys and launched in 2022 to produce high quality parts in multiple sectors. While a range of mechanical, thermal and chemical processes have been considered for recycling of polyamides, this paper focuses on the mechanical fragmentation and thermal extrusion for recycling PA12 to produce fused deposition modelling (FDM) filament, enabling the reuse of materials within 3D printing processes across a range of industrial sectors. The PA12 will go through unique changes during the SAF process which impacts the quality of recycled materials that can be produced for FDM filament production. This paper assesses the impact of these changes as well as those caused by fragmentation and extrusion on the recycled material properties and identify process parameters which influence the quality and consistency of filament production.

Keywords: Polyamide 12, Filament Extrusion, Circular Economy, Polymer Recycling.

A Study on the Effects of Fibre Orientation and Layer Stacking Sequence on Mechanical and Energy Performance of CFRCs
(ID 179)

Sadik Sayin (University of Birmingham); David Butler (University of Birmingham); Shoaib Sarfraz (University of Birmingham)*

Abstract. Carbon Fibre-Reinforced Composites (CFRCs) offer exceptional strength-to-weight ratios; however, optimising their mechanical performance while managing energy demands in additive manufacturing remains a significant challenge. Guided by Classical Laminate Theory (CLT), this study investigates the influence of fibre orientation and stacking sequence on the tensile behaviour of 3D-printed CFRCs. Test specimens were fabricated using a Markforged Mark Two printer and subjected to uniaxial tensile testing. Configurations featuring 0°/45° orientations alternating every layer demonstrated the highest tensile strength and stiffness, followed by 0°/90°, while 45°/90° layups demonstrated the weakest performance. The superior performance of the alternating-every-layer sequences is attributed to improved stress distribution and enhanced interlaminar cohesion. Although energy consumption between tested configurations was minimal, a broader comparison of manufacturing methods revealed substantial variation. Resin Transfer Moulding proved the most energy-efficient; Autoclave Curing required significantly higher energy despite yielding superior part quality; and 3D printing, while offering customisation, was constrained by energy intensity and mechanical variability. These findings offer valuable insights for balancing mechanical performance with energy efficiency in CFRC production, contributing to more sustainable composite design strategies.

Keywords: CFRCs, Fibre Orientation, Stacking Sequence, Additive Manufacturing, Energy Efficiency.

Evaluation of the potential of Large-Scale 3D Printing to promote a circular economy of PET Plastic Bottles: comparison between European and North American Context
(ID 115)

Catalina Suescun Gonzalez (Université de Lorraine)*; Aditi Basdeo (Western University); Alessia Romani (Western University); Fabio Cruz Sanchez (Université de Lorraine); Cécile Nouvel (Université de Lorraine); Hakim Boudaoud (Université de Lorraine); Joshua Pearce (Western University)

Abstract. The increasing accumulation of plastic waste has intensified the urgency for sustainable recycling solutions. Among these, Distributed Recycling for Additive Manufacturing (DRAM) has emerged as a promising approach to revalorize post-consumer plastic waste in a closed loop. This study evaluates the potential of the DRAM model in the European and North American contexts, specifically for the recycling of post-consumer plastic bottles composed of polyethylene terephthalate (PET) for the body and high-density polyethylene (HDPE) for the cap, without prior material separation. More precisely, the research analyzes the efficiency and requirements to develop a plastic circular loop in France and Canada. A methodology was developed to assess the collection, transformation, and 3D printing of the recycled bottles, incorporating modifications to enhance 3D printer performance and material processing. Functional objects were 3D printed to assess practical applications, producing furniture and decorative products. The findings indicate that, while DRAM can be adapted to different regional contexts, standardized material preprocessing, optimized 3D printing extrusion parameters and enhanced flow monitoring are critical to improving reproducibility. This study contributes to advancing circular economy practices, providing a scalable and sustainable strategy for plastic waste valorization through additive manufacturing.

Keywords: Distributed Recycling for Additive Manufacturing (DRAM), closed-loop recycling, Fused Granular Fabrication (FGF), Fused Particle Fabrication (FPF), Material Extrusion (MEX)

Paper Session 3: Digitalization
Wed, 10th September - 11:00 - 13:00

Aula B

Case Study Analyses of Benefits and Barriers of Circular Manufacturing Systems: A Step Towards a Simulation-Based Approach
(ID 37)

Jorge Cabello Oqueña (University of Twente)*; Shun Yang (University of Twente); Sebastian Thiede (University of Twente)

Abstract. The industry's circularity transition is a critical but challenging issue in Circular Manufacturing Systems (CMS) mainly due to increased process complexity and high uncertainties, particularly but not limited to the quantity and quality of returned products. This study applies the PRISMA framework to identify the most significant drivers and barriers on industry-based case studies. A systematic review of case studies indicates that while circular practices increase process complexity, they also offer other benefits, such as cost savings. To address these challenges, this research proposes a simulation-based analysis focused on uncertainty management. The outcomes offer practical recommendations for companies to address these challenges through structured steps in a discrete simulation environment.

Keywords: Sustainability, Circular Economy, Circular Manufacturing Systems, Uncertainty Management, Simulation-Based Analysis.

Digitization in Serial Timber Construction Manufacturing: A Model-Based Approach for Sustainable and Efficient Production
(ID 182)

Nicole Oertwig (Fraunhofer IPK)*; Valentin Eingartner (TU Berlin); Holger Kohl (Fraunhofer IPK)

Abstract. Progressing climate change and increasing resource scarcity demand efficient, scalable, and resource-conscious manufacturing concepts in serial timber construction. A key challenge lies in the seamless integration of design and material data into the manufacturing process to maximize material efficiency, minimize waste, and ensure environmentally friendly production. By employing integrated modelling techniques, relevant information from design and material logistics can be seamlessly incorporated into manufacturing. This enables optimized material utilization, a reduction in offcuts and waste, and the targeted selection of sustainable raw materials. Additionally, the use of real-time data and intelligent information and communication technologies (ICT) enhances production process control, reduces energy consumption, and minimizes inefficient rework. A prerequisite for these efficiency and sustainability improvements is the comprehensive digitalization of relevant information flows along the value chain. This paper presents a model-based approach for assessing the degree of digitalization in serial timber construction manufacturing. The underlying reference model facilitates a systematic assessment of existing digitalization gaps and derives specific recommendations for closing them. The goal is to establish a data-driven, resource-efficient, and low-emission manufacturing process that integrates ecological, economic, and social sustainability aspects.

Keywords: Serial Timber Construction, Digitalization Assessment, Reference Model.

Digitalizing Circular Construction: Operationalizing Circularity Metrics through BIM and BI–Integrated Workflows in Timber Prefabrication
(ID 195)

Johannes Reinders (Technische Universität Berlin)*

Abstract: The Built Environment (BE) plays a crucial role in greenhouse gas (GHG) emissions, resource consumption, and waste generation. Circular Construction (CC) and Timber Construction with Prefabricated Components (TCPC) are seen as key contributors to curb these environmental hazards. Digital workflows are seen as major enablers for circularity in TCPC. However, the integration of effective assessment procedures for CC into digital design workflows remains insufficient. This project addresses this gap by proposing a prototypical digital workflow that enables real-time assessment of circularity performance through the operationalization of circularity metrics. Utilizing Building Information Modeling (BIM) and Business Intelligence (BI) technologies, two selected metrics from the DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen) Circularity Index (ZI), Material Origin and Recyclability, were operationalized.
The four-stage workflow, comprised of semantic BIM modelling, Life-Cycle-Assessment (LCA) data mapping, circularity metric computation, and BI visualization was implemented on an exemplary component catalogue. The prototypical implementation demonstrated the feasibility of integrating circularity metrics into digital design workflows, by showcasing real-time, component-level evaluation. Despite the limited scope of the research with focus on two metrics and a small component catalogue, the workflow exhibits considerable potential in replicability. Future work could aim to expand the metric library, validate the effects with larger-scale case studies and minimize technical requirements. Ultimately, future developments could enable continuous assessments of a variety of trade-offs during planning with reduced efforts, thereby streamlining the evaluation of design alternatives and enabling more efficient data-driven planning decisions.

Keywords: Circular Construction, Timber Prefabrication, Building Information Modeling (BIM), Circularity Metrics, Sustainable Building Design

Utilizing manufacturing digital twins for sustainability reporting
(ID 151)

Yujia Luo (York St John University); Juan Ramon Candia (University of Leeds); Peter Ball (University of York)*

Abstract. The advance of digital technologies and the societal imperative to achieve sustainability exposes new pathways for businesses. The environmental and social impacts of industrial operations are well known and there are increasing demands to report impact through voluntary and mandatory corporate stakeholder reporting. The extensive live operations reporting is disconnected from corporate reports built retrospectively from aggregate enterprise data. This paper argues that the disconnect between operations and corporate reporting is a missed opportunity hindered by data integration, absence of frameworks to guide adoption and the missed value that comes from integrated reporting. By considering digital twin data and those of reporting standards such as the EU's Environmental Sustainability Reporting Standard, the two could be mapped. Once mapped, a digital twin could be created to generate reporting data and enable improvement evaluation. This paper uses literature and expert interviews to report the requirements for linking digital twins to sustainability reporting. In turn it proposes a framework to guide data mapping and model configuration to use to evaluate the business level impact of operational changes. A discussion on the utility of the framework precedes the conclusion with directions for future research.

Keywords: Digital twins, sustainability reporting, manufacturing systems.

Exploring the Role of DPPs in Smart Circular Economy: a conceptual Synthesis
(ID 194)

Luana Coelho de Morais (São Carlos School of Engineering, University of São Paulo); Carlos Eduardo Silveira (São Carlos School of Engineering, University of São Paulo); Maxim Mintchev (Technische Universität Berlin); Ana Carolina Bertassini (Chalmers University of Technology); Meire Ramalho de Oliveira (Federal Institute of Sao Paulo); Holger Kohl (Technische Universität Berlin); Mateus Cecílio Gerolamo (São Carlos School of Engineering, University of São Paulo)*

Abstract. This article presents a systematic literature review (SLR) examining the strategic role of Digital Product Passports (DPPs) in enabling transitions to Smart Circular Economies (SCE). The study synthesizes recent research on the conceptual foundations, regulatory drivers, technological enablers, lifecycle integration, sectoral applications, and organizational challenges of DPP adoption. DPPs are conceptualized as dynamic, interoperable digital records linked to unique product identifiers, facilitating multidimensional traceability across product lifecycles. Despite significant progress driven largely by European Union policies, barriers related to digital infrastructure, governance, cultural readiness, and stakeholder engagement persist—particularly in Global South contexts. The proposed conceptual synthesis integrates technological, organizational, market, and regulatory dimensions, emphasizing the critical role of change management and collaborative governance. The review highlights gaps in empirical research on downstream actors and behavioral factors, and calls for interdisciplinary approaches to address socio-technical complexities. Findings suggest that realizing the full transformative potential of DPPs requires coevolution of technology, organizational culture, and inclusive policy frameworks, supported by future empirical studies focused on diverse economic and institutional settings.

Keywords: Digital Product Passport, Smart Circular Economy, Traceability, Organizational Change, Socio-Technical Systems

Wednesday, 10th September - 14:00 - 16:00		
Paper Session 4 **Circular Evaluation**	**Paper Session 5** **Additive Manufacturing II**	**Paper Session 6** **Sustainable Corporate Transformation**
Performance assessment of circular supply chain transition: A systematic literature review and future research directions (ID 165)	Use Cases for data spaces to support sustainable engineering decisions in additive manufacturing (ID 47)	The need to integrate sustainable leadership into sustainable manufacturing (ID 137)
Cost and environmental impact savings enabled by Industrial Symbiosis implementation (ID 77)	Enhancing Powder Recycling in Sustainable Laser Powder Bed Fusion of 316L Stainless Steel (ID 16)	Validating Behavioural Model of Rational Choice for Net Zero Manufacturing: An Action Research Approach (ID 144)
Quantifying Circularity and Recycling Efficiency: Comparing recent Methodologies from the manufacturing perspective (ID 96)	Prospective In-situ monitoring and control of residual stress for a sustainable PBF process: A critical review (ID 152)	Driving Sustainability with Green Lean Six Sigma: A DMAIC-Based Approach (ID 157)
A method for assessing circularity, environmental and social sustainability of manufacturing systems (ID 175)	Evaluating Mechanical Performance and Sustainability in Metallic Additive Manufacturing: A Comparative Study of Selective Laser Melting and Wire Laser Metal Deposition (ID 73)	Corporate Sustainability: A Procedure Model for Strategy Development and Implementation (ID 25)
Design of Multi-Criteria Decision Making Model for Global and Closed-Loop Supply Chain Networks Considering GHG Emissions, Recycling Rate, and Costs Using Linear Physical Programming (ID 190)	The production of nickel-free stainless steel medical implants: demonstrator and life cycle assessment (ID 119)	A Structured aFramework for Net Zero Transition in Manufacturing (ID 126)
Modeling product returns in remanufacturing: a Markov chain approach (ID 168)		A Sustainable Business Model for Green Energy Transition and Advanced Manufacturing Development in Emerging Economies: A Case of ESKOM in South Africa (ID 123)

Paper Session 4: Circularity Evaluation
Wed, 10th September - 14:00 - 16:00

Aula A

Performance assessment of circular supply chain transition: A systematic literature review and future research directions
(ID 165)

Alice Grano (University of Applied Sciences Wiener Neustadt)*; Selim Erol (University of Applied Sciences Wiener Neustadt); Gerald Reiner (Vienna University of Economics and Business)

Abstract. Circular supply chains (CSCs) are essential elements for implementing circular practices. Accordingly, different approaches are available in academic literature that offer orientation among criteria for assessing CSC performance. Yet, implementing CSCs is an ongoing process and many companies find it difficult to plan short- and mid-term developments in the initial transition phase due to their complexity and dynamics. However, a preliminary literature review did not reveal any specific consideration of this issue in existing performance measurement systems. In order to assess and systematize the state of the literature on environmental, economic, and social performance assessment in SC transition and detect related research gaps, a systematic literature review (SLR) of peerreviewed articles and conference proceedings published in the Scopus database (2015-2025) was conducted drawing on a Resource-Based View (RBV) and the lens of Transition Management Theory (TMT). First results show a focus on CSC assessment in post-implementation state, but the literature only marginally considers how key performance and sustainability measures, e.g. carbon footprint or cost-related indicators, develop during transition and how assessment results may vary in time. Accordingly, further research should be conducted to analyze the phase of CSC transition, which is expected to be particularly pronounced for slow moving goods.

Keywords: Circular Supply Chains, Sustainability, CE transition.

Cost and environmental impact savings enabled by Industrial Symbiosis implementation
(ID 77)

Maria Gloria Trapani (University of Palermo)*; Simone Amantia (University of Palermo); Gianni Campatelli (University of Florence); Livan Fratini (University of Palermo); Giuseppe Ingarao (University of Palermo)

Abstract. Industrial waste generation poses a growing environmental and economic challenge, with manufacturing activities contributing significantly to metal waste production. A large portion of materials never reach the final product, and conventional recycling methods for metals, such as remelting, are energy-intensive and result in substantial material losses. To overcome such losses circular economy logic is mandatory in the near future. By rethinking waste management within manufacturing, it is possible to move toward a more resourceefficient and circular industrial system. One promising solution is indeed Industrial Symbiosis, which shifts the perspective of waste from a burden to a resource that can be reintegrated into other manufacturing processes. This approach promotes the exchange of materials, energy, and services between industries, with the aim of reducing waste generation and optimizing resource use. However, still some issues affect the implementation of industrial symbiosis. In the present work both the environmental impact and associated costs have been evaluated in a comparative perspective analyzing a conventional manufacturing approach versus a symbiotic one. The analysis aims to demonstrate the applicability of industrial symbiosis, considering a given case study, and shows how industries can reduce waste and lower energy consumption, but an increasing cost is observed due to the lack of industrial practices and non-dedicated machines.

Keywords: Industrial symbiosis, Cost assessment, Environmental impact.

Quantifying Circularity and Recycling Efficiency: Comparing recent Methodologies from the manufacturing perspective
(ID 96)

Christoph Kirschner (Graz University of Technology); Verena Schnaitter (Graz University of Technology); Kai Rüdele (Graz University of Technology)*

Abstract. The European Clean Industrial Deal underscores the need for highquality recycling and circular material use to achieve climate neutrality in industry´s value chains. A key challenge in this transition is the development of robust methodologies to assess recycling quality, material circularity, and climate impact. The European Environment Agency (EEA) has recently introduced a framework for assessing recycling quality, focusing on material recovery efficiency, environmental impact, and overall recyclability to improve circular economy strategies. This framework provides a structured approach to evaluating recycling processes and their contribution to resource conservation. Independently of this framework, other concepts and assessment methods for defining and measuring circularity and climate neutrality have been developed by different researchers and organizations. This paper examines the strengths, limitations, and synergies between these frameworks and methodologies, providing insights for sustainable manufacturing. The findings of this comparative analysis emphasize the necessity of integrating recycling efficiency metrics into broader circular economy and climate impact assessments. Our research contributes to the development of holistic sustainability strategies and promotes the advancement of more effective sustainability frameworks that support the industrial transformation envisioned in the European Clean Industrial Deal.

Keywords: recycling quality, measuring circularity, climate neutrality

A method for assessing circularity, environmental and social sustainability of manufacturing systems
(ID 175)

Athanasios RENTIZELAS (National Technical University of Athens)*; Eleni Aretoulaki (National Technical University of Athens); Kostas Florios (National Technical University of Athens); Efthimis Simos (National Technical University of Athens)

Abstract. Assessing the sustainability performance of manufacturing systems has mostly focused on the Triple Bottom Line dimensions. However, little emphasis has been placed in assessing circularity together with sustainability and in highlighting the tradeoffs that may exist between different assessment dimensions. This study presents a generic method aimed at facilitating integrated assessment of circularity, environmental and social sustainability specifically focused on manufacturing systems. The method consists of a list of indicators defined for each of the three assessment dimensions, classified in key categories. The categories' importance is obtained through a survey with experts from the manufacturing sector. Subsequently, the survey outcomes are processed using the Best-Worst Method, a multi-criteria decision-making method, to obtain the weights for each indicator category. A case study application, serving as a worked example of the method, is presented to facilitate understanding of its operation and utility. The method can support effective assessment of manufacturing systems' sustainability performance, while at the same time considering circularity performance and highlighting the potential tradeoffs.

Keywords: Circular economy, sustainability, manufacturing, multi-criteria.

Design of Multi-Criteria Decision Making Model for Global and Closed-Loop Supply Chain Networks Considering GHG Emissions, Recycling Rate, and Costs Using Linear Physical Programming
(ID 190)

Hiromasa Ijuin (Chiba Institute of Technology); Yuki Kinoshita (The University of Electro-Communications)*; Tetsuo Yamada (The University of Electro-Communications); Surendra Gupta (Northeastern University)

Abstract. Current economic activities with mass production and consumption exacerbate global warming and resource depletion. At the 29th Conference of the Parties (COP 29) to the United Nations Framework Convention on Climate Change, The Breakthrough Agenda announced that governments from 61 supporting countries, representing 80% of global Greenhouse Gas (GHG) emissions, have agreed on priority actions to cut GHG emissions. COP 29 discussions highlighted the need to consider the global supply chain in reducing greenhouse gases. Global supply chains generate GHG emissions through manufacturing processes across multiple countries. Conversely, reverse supply chains recover End-of-Life (EOL) products, enabling resource recovery and GHG emission reduction through recycling. Manufacturing Decision Makers (DMs) face the challenge of designing environmentally friendly and economical Global and Closed-Loop Supply Chain (GCLSC) networks, where GHG reduction, increased recycling rates, and cost decrease often conflict. This study designs a GCLSC network considering material-based GHG emissions and the entire recycling rate by Linear Physical Programming (LPP) for multi-criteria decision-making in its objective function. First, the GCLSC network is modeled and described using integer programming. Next, objective functions are formulated using LPP to minimize GHG emissions and total cost, and to maximize the recycling rate. Finally, numerical experiments evaluate the GCLSC network.

Keywords: Supply Chain, End-of-Life Product (EOL), Life Cycle Assessment (LCA), Supplier Selection, Material Recovery, Integer Programming.

Modeling product returns in remanufacturing: a Markov chain approach
(ID 168)

Siegfried Eisele (Technical University of Applied Sciences Augsburg)*; Jianing Zhang (Technical University of Applied Sciences Augsburg); Frank Danzinger (Technical University of Applied Sciences Augsburg)

Abstract. Handling uncertainty when and under which conditions products are circulated for remanufacturing is a major challenge. Stochastic models need to address the complexity of the product life cycle and additionally, accomplish the cold start problem, defined by the fact that historical data is often scarcely available. This paper explores how Markov chain modeling captures the stochastic nature of product life cycles under the constraints of the cold start problem. Our analysis reveals that simulated time-inhomogeneous discrete Markov chains with stochastic transition probabilities integrate the aspects of product aging, the property of closed loop product circulation and product remanufacturing by resetting the products to like-new conditions into one holistic model. Moreover, experts can still resort to well-understood probability distributions since they can be converted to transition probabilities needed by Markov chains. These findings suggest that our Markov chain model has the potential to become a reference model for equivalent problems like reusing or repurposing since its flexibility allows for extending to other stochastic distributions and additional states in the circular loop.

Keywords: circular Economy, remanufacturing, time-inhomogeneous Markov chain

Paper Session 5: Additive Manufacturing II
Wed, 10th September - 14:00 - 16:00

Aula Magna

Use Cases for data spaces to support sustainable engineering decisions in additive manufacturing
(ID 47)

Iris Gräßler (Universität Paderborn); Carmen De Groote (Universität Paderborn)*; Sven Rarbach (Universität Paderborn)

Abstract. The integration of life cycle data in product engineering to reduce environmental impact is currently undervalued. Data spaces allow relevant data to be exchanged through the value creation network. Additive Manufacturing (AM) generates large amounts of data that can be made available for eco-design decisions, such as optimizing environmental footprint or recyclability. A structured list of use cases is not yet compiled. In this paper, use cases are systematically identified and verified by a twofold approach: Firstly, a systematic literature review is conducted identifying existing approaches for the engineering process at the interfaces of the three domains: data spaces, product life cycle data and AM. Secondly, a survey is conducted at the trade fair “Formnext 2024” identifying data-related challenges that AM companies face in sustainable product engineering. Use cases are derived from the literature and verified by the survey’s findings. It can be concluded that singular approaches exist, but only for partial aspects of using data spaces in AM. A structured list of use cases based on literature and considering the challenges disclosed by the survey is compiled. Similar to checklists, engineers can derive requirements from this list for further development andstandardization of data space technologies within AM.

Keywords: data space, additive manufacturing, sustainability.

Enhancing Powder Recycling in Sustainable Laser Powder Bed Fusion of 316L Stainless Steel
(ID 16)

Tingting Huang (National University of Singapore)*; Jerry Ying Hsi Fuh (National University of Singapore); Heow Pueh Lee (National University of Singapore)

Abstract. The sustainability of laser powder bed fusion (LPBF) additive manufacturing relies heavily on optimizing powder recycling to minimize waste and ensure consistent part quality. This study investigates the effects of repeated powder reuse on 316L stainless steel, focusing on the interplay between powder management protocols and laser scanning strategies across multiple LPBF cycles. Residual powder was systematically recycled using standard sieving and blending methods, with morphological evolution monitored throughout the process. Two distinct laser rotation strategies were evaluated to determine their compatibility with powder aging trends, while mechanical performance of printed parts was assessed under both as-built and post-treated conditions.

Key findings highlight the importance of angular laser strategy selection in mitigating property anisotropy, with one approach showing superior stability across reuse cycles compared to the other. Controlled powder drying during recycling was found to enhance mechanical performance by addressing moisture-related processing challenges. The results demonstrate that strategic integration of powder conditioning and process parameter optimization can sustain part integrity over extended reuse periods, advancing LPBF’s economic and environmental viability without sacrificing performance.
This work provides a framework for balancing operational efficiency and material sustainability in metal additive manufacturing, offering practical guidelines for industry adoption.

Prospective In-situ monitoring and control of residual stress for a sustainable PBF process: A critical review (ID 152)

Farshad Samadpour Samarin (Purdue University)*; Hazim El Mounayri (Purdue University)

Abstract. Residual stress (RS) significantly impacts the mechanical performance and di-mensional stability of laser powder bed fusion(LPBF) components. This paper critically reviews the influence of key process parameters, current predictive modeling techniques, and state-of-the-art sensing technologies for in-situ moni-toring. Modeling approaches including analytical methods, finite element simula-tions, and machine learning strategies are discussed, with an emphasis on recent advances in physics-informed frameworks. Furthermore, emerging sensing tech-niques—visual, thermal, and acoustic—are evaluated for their potential to monitor RS during fabrication. Recognizing the limitations of current methods, a novel multi-sensor, physics-informed real-time monitoring and adaptive control strategy is proposed. This framework offers a path forward to achieve dynamic RS miti-gation, advancing the reliability and industrial scalability of LPBF processes.

Keywords: Residual Stress, In-Situ Monitoring, Laser Powder Bed Fusion.

Evaluating Mechanical Performance and Sustainability in Metallic Additive Manufacturing: A Comparative Study of Selective Laser Melting and Wire Laser Metal Deposition (ID 73)

Leopoldo De Bernardez (ITBA)*; Cristian Sandre (ITBA); Juan Sanguinetti (ITBA); Sebastian Mur (ITBA)

Abstract. Additive manufacturing has become a key technology in numerous industrial sec-tors, driven by the increasing use of metallic materials. Its significant advantages, such as increased design flexibility, reduced material usage, and improved cus-tomization possibilities, highlight its potential to revolutionize traditional manu-facturing processes. This study presents a comparative analysis of two additive manufacturing processes, namely selective laser melting and wire laser metal deposition. Both methods allow the manufacture of complex parts and leverage the benefits of topology optimization. The study focused on 316L stainless steel applications and analyzed both the mechanical properties and the material and en-ergy consumption required for its production, based on experimental measure-ments and literature data. Differences in tensile behavior, as well as energy and material efficiency between the two processes, are analyzed. A decision matrix is proposed to aid in the selection of the most appropriate manufacturing process for the case under study. The need to assess environmental impact alongside mechan-ical performance when selecting additive manufacturing technologies is ad-dressed, thus contributing to the development of more sustainable manufacturing practices.

Keywords: Additive manufacturing, SLM, WLMD, Sustainability, Mechanical performance.

The production of nickel-free stainless steel medical implants: demonstrator and life cycle assessment (ID 119)

Brent Hendrickx (KU Leuven University)*; Pooya Hosseini (KU Leuven University); Tomi Lindroos (VTT); Atte Antikainen (VTT); Joost Duflou (KU Leuven University); Andoni Sanchez-Valverde (Outokumpu); Xuan Yang (Outokumpu Nirosta Gmbh)

Abstract. This study evaluates the environmental impact of using nickel-free stainless steel powder for producing medical implants, focusing on additive manufacturing (AM) of stabilizer brackets used in the Nussbar procedure. Currently, titanium-based implants produced via CNC milling form the alternative for nickel-allergic patients, but their production is associated with high environmental impacts. A comparative life cycle assessment (LCA) was conducted on three production routes: CNC-milled titanium, electron beam melted (EBM) titanium, and selective laser melting (SLM) of a nickel-free stainless steel. The results demonstrate that LPBF of the nickel-free alloy significantly reduces CO_2 emissions (by 69% vs. CNC titanium and 58% vs. EBM titanium) and overall environmental impact. The findings highlight the potential of lower-impact materials in reducing the carbon footprint of healthcare for select use-cases.

Keywords: : Life Cycle Assessment, Additive Manufacturing, Medical Implant

Paper Session 6: Sustainable Corporate Transformation
Wed, 10th September - 14:00 - 16:00

Aula B

The need to integrate sustainable leadership into sustainable manufacturing (ID 137)

Anna Nowak-Meitinger (TH Wildau)*; Alexander Lübbe (TH Wildau); Sabine Ammon (TU Berlin)

Abstract. In manufacturing industry, many companies are striving for sustainability in order to support the achievement of the 17 SDGs and sustainable development. The existing scientific discourse on sustainable manufacturing (SM) often focuses on economic and environmental aspects with a technologycentered perspective. It either provides abstract and generic results or mathematical, measurable solution models. A human-centered focus and a leadership perspective with its social and qualitative concepts and its emphasis on values and ethics are rarely considered. This paper gives a general overview of the gaps and links between SM and sustainable leadership (SL) and how both can contribute to each other. We argue that the integration of a SL perspective is essential to comprehensively implement SM in all three dimensions of sustainability, i.e., economic, ecological and social. We propose the development of a structural information model to capture the complexity and increase judgment in decision-making in SM. Our proposal is to use the design science research methodology and model-based systems engineering to identify and formalize relationships between elements and effect structures in order to capture knowledge. It is shown that SL is linked to existing components and criteria of SM and can thus broaden and complement the field of research.

Keywords: human centricity, systems thinking, sustainable management, sustainable production, MBSE, SysML.

Validating Behavioural Model of Rational Choice for Net Zero Manufacturing: An Action Research Approach (ID 144)

Reet Kaur (Cranfield University); Marie Wells (The Manufacturing Technology Cenatre); Ruby Maxfield (The Manufacturing Technology Centre); Justyna Rybicka (The Manufacturing Technology Centre); John Patsavellas (Cranfield University); Konstantinos Salonitis (Cranfield University)*

Abstract: This paper presents the methodological approach and findings from an action research study conducted to validate the Behavioural Model of Rational Choice for Net Zero Manufacturing framework. The research was implemented at a leading UK manufacturing technology centre specialising in transformative manufacturing technologies. The study examined how the framework manifested in practice during the development of the organisation's internal net zero strategy. The primary aim was to understand whether this framework helped overcome contributing elements of bounded rationality—complexity, information asymmetry, and cognitive biases—that typically hinder net zero strategic decision-making in manufacturing contexts. The action research methodology enabled framework refinement while simultaneously supporting the organisation's net zero objectives. Data collection involved stakeholder interviews, process documentation, and outcome assessments over a 3-month period. This paper contributes to the understanding of strategic decision-making in net zero manufacturing contexts and provides methodological insights for framework validation in industrial settings.

Keywords: action research, bounded rationality, cognitive biases, decision-making frameworks, framework validation, information asymmetry, net zero complexity, net zero strategy.

Driving Sustainability with Green Lean Six Sigma: A DMAIC-Based Approach
(ID 157)

Tamer Abdulghani (Brandenburgische Technische Universität Cottbus-Senftenberg)*; Tobias Isau (Brandenburgische Technische Universität Cottbus-Senftenberg); Herwig Winkler (Brandenburgische Technische Universität Cottbus-Senftenberg)

Abstract. Striving for a carbon-neutral and competitive existence necessitates a strategic approach that improves sustainability without compromising efficiency. Lean Six Sigma (LSS) is widely adopted to drive operational efficiency, increase cost-effectiveness, and improve quality; however, it is also challenged by a lack of focus on managing environmental sustainability issues. Consequently, the need to integrate sustainability into LSS has become a critical concern for organizations. Green Lean Six Sigma (GLSS) is a strategy that integrates aspects of Lean, Six Sigma, and sustainable practices, employing the DMAIC approach (Define, Measure, Analyze, Improve, Control) to enhance the efficiency of operations while reducing waste and environmental impact. For this purpose, a systematic literature review including bibliometric and content analysis was conducted to identify how the integration of Green Lean Six Sigma within the DMAIC approach influences organizational sustainability performance, and what barriers are associated with its effective implementation. The results indicate that the incorporation of GLSS significantly improves sustainability performance. The analysis identified several key success factors, including leadership commitment, identification of sustainability metrics, employees training, and choosing suitable GLSS tools carefully to suit specific sustainability goals. However, some challenges were also identified, including change resistance and insufficient knowledge of training required.

Keywords: Sustainability, Green Lean Six Sigma, DMAIC, Systematic Literature Review.

Corporate Sustainability: A Procedure Model for Strategy Development and Implementation
(ID 25)

Felix Budde (Fraunhofer IPK)*; Ronald Orth (Fraunhofer IPK); Lina Stockmann (Fraunhofer IPK)

Abstract. Developing and implementing a sustainability strategy is a critical challenge for companies striving to align their operations with environmental, social, and governance (ESG) principles. With increasing regulatory requirements, such as the Corporate Sustainability Reporting Directive (CSRD), the need for a structured and effective approach has become more relevant than ever. This paper presents a model designed to assist organizations in systematically developing and integrating a sustainability strategy. The model is derived from a comprehensive literature review of existing frameworks, identifying key components and best practices. The result is a procedure model including (1) preparation, (2) strategy development, (3) strategy implementation and (4) reporting and communication.

Keywords: Sustainability Management and Strategy, Procedure Model.

A Structured aFramework for Net Zero Transition in Manufacturing
(ID 126)

John Patsavellas (Cranfield University)*; Rashmeet Kaur (Cranfield University); Konstantinos Salonitis (Cranfield University)

Abstract. Despite increasing pressure to decarbonise, manufacturing organisations globally lack standardised frameworks to benchmark their overall progress toward net zero goals, relying instead on fragmented, process-oriented models. To address this gap, this paper introduces the Net Zero Maturity Model (NZMM), a structured framework designed to help manufacturing organisations evaluate their current maturity levels and select the most pertinent strategic actions toward net zero by avoiding prioritisation conundrums. The NZMM was developed through an extensive literature review that identified key thematic areas critical for net zero manufacturing, validated and ranked through input from 30 recognised industry practitioners. The resulting model integrates three maturity levels across seven key dimensions, addressing Scope 1, 2, and particularly the complexities in Scope 3 emissions. The framework serves as a practical decision-making tool to reduce uncertainty and facilitate structured decision-making, allowing organisations to gauge their net zero maturity and systematically navigate capability development. Validation with two manufacturing organisations demonstrated the NZMM's effectiveness in identifying capability gaps and prioritising improvement initiatives. The NZMM contributes to existing literature and industry practice by introducing a cohesive, standardised approach that bridges the gap between narrowly-focused, process-specific models and holistic organisational assessment needs.

Keywords: net zero manufacturing, maturity model, decarbonisation

A Sustainable Business Model for Green Energy Transition and Advanced Manufacturing Development in Emerging Economies: A Case of ESKOM in South Africa
(ID 123)

Genevieve Bakam (Tshwane University of Technology)*; Gift Nenzhelele (Tshwane University of Technology); Khumbulani Mpofu (Tshwane University of Technology)

Abstract. Traditional business models are replaced with sustainable business models to ensure socioeconomic and environmental considerations in manufacturing processes. This study provides a sustainable business model for green energy transition and advanced manufacturing development in emerging economies. This study uses existing local and global frameworks to conceptualise a sustainable business model enabling a localized green energy adoption. The case study of Eskom, the national electricity company in South Africa is applied to investigate green energy transition practices and the shift towards advanced manufacturing. Findings showed that the Green Energy Transition sustainable business model (GET-SBM) includes dimensions of green manufacturing, technology innovation, localization and energy value proposition following decentralized ownership, collaborative ecosystem, privatization and stakeholder involvement. Local requirements like the Just Energy Transition Strategies, National Development Plan and the integrated resource plan are supported by the smart solutions offering Energy, product and infrastructure as a service (EaaS, PaaS and IaaS) to create affordability, agility and customer ownership. The government should promote public-private partnerships, community energy projects, upgraded infrastructure and network privatization to optimise the green energy transition. The repurposing of coal-fired power stations should compensate job losses after decommissioning. Sustainable energy models should be liberalized to manage the initial high cost of green implementation.

Keywords: Sustainable business model, Green energy, Advanced manufacturing, ESKOM and South Africa.

Wednesday, 10th September - 16:30 - 18:30		
Paper Session 7 **Value Retention Processes**	**Paper Session 8** **Manufacturing Processes**	**Paper Session 9** **Green Energy Systems**
Disassembly Depth as a Determinant of Reassembly Performance in Remanufacturing Systems (ID 61)	Data-driven energy consumption modeling of injection molding machine modules (ID 33)	Characterization of the Calendering Process for Sulfide-Based Solid-Electrolyte Separators (ID 108)
Using Stable Diffusion based Augmentation for Visual Wear Classification in Remanufacturing (ID 78)	INFLUENCE OF PROCESS PARAMETER VARIATION IN TURNING PROCESSES ON THE LIFE CYCLE ASSESSSMENT (ID 102)	Development of sustainable aluminium foam components infiltrated with paraffin for battery housings (ID 98)
End-of-life decision-making in circular manufacturing: A Complex adaptive system of systems perspective (ID 81)	Sustainability Index-Based Characterization of Al 3003 part in Die-Press versus Incremental Sheet Forming (ID 112)	Optimised and skill-based task allocation for the hybrid assembly of a water electrolyser in a human-robot interaction cell (ID 44)
End-of-Life Calculator: Aircraft Seat Case Study (ID 159)	Dual-Robot Wiring for High-Speed Control Cabinet Assembly (ID 158)	Social acceptance of green hydrogen in decentralized energy system - a case study of Ghana (ID 91)
Sustainability Assessment of End-of-Life Strategies for PEM Fuel Cells (ID 23)	Harvesting Nature's Red Gold: An Environmental Assessment of Lycopene Conventional Extraction (ID 51)	Higher Sustainability For Energy Systems And Business Models: The Role Of Harmonic Mitigation For The Use Of Green Electricity (ID 9)
Recovery of NdFeB Magnets from the Ferrous Fraction of Shredded Waste Streams by Physical Sorting (ID 1)		

Paper Session 7: Value Retention Processes
Wed, 10th September - 16:30 - 18:30

Aula A

Disassembly Depth as a Determinant of Reassembly Performance in Remanufacturing Systems (ID 61)

Maik Nuebel (IFA - Institute of Production Systems and Logistics)*

Abstract. Remanufacturing offers the potential to reduce dependency on raw material suppliers and represents an element in the transition toward a sustainable circular economy. A key challenge is the synchronization of disassembly and assembly processes, which is essential for the efficiency and effectiveness of remanufacturing systems. One promising approach is to increase productivity by reducing the disassembly depth through the omission of certain disassembly steps. However, such a reduction must be closely aligned with the requirements of the subsequent assembly process. This paper investigates the impact of varying disassembly depths on the assembly process. Therefore, the process is presented, and the corresponding workload distributions are systematically analyzed. The findings demonstrate that decreasing disassembly depth results in reduced throughput times and enhanced workload flexibility within the process. This flexibility arises from the dynamic use of subassemblies and contributes to workload balancing within the assembly system. A final simulation-based validation highlights these effects and underscores the potential role of subassemblies in generating efficient and effective remanufacturing systems.

Keywords: remanufacturing; reassembly; disassembly depth; load flexibili

Using Stable Diffusion based Augmentation for Visual Wear Classification in Remanufacturing (ID 78)

Engjëll Ahmeti (Fraunhofer Institute for Manufacturing Engineering and Automation IPA)*; Maximilian Herold (Fraunhofer Institute for Manufacturing Engineering and Automation IPA); Jan Koller (Fraunhofer Institute for Manufacturing Engineering and Automation IPA); Frank Döpper (Fraunhofer Institute for Manufacturing Engineering and Automation IPA)

Abstract. The increasing demand for raw materials and shorter product cycles have driven the advancement of the circular economy, with the European Union focusing on reducing raw material consumption and ensuring the circularity of products and components. Remanufacturing, a key element of circular economy, faces challenges in assessing the condition of products and components, a process traditionally carried out manually, requiring expert knowledge. This paper aims to address the lack of diverse datasets by generating synthetic datasets to enable AIsupported visual inspections in remanufacturing. Specifically, this paper focuses on generating realistic wear patterns, in the example of corrosion effects, with starter motors as the reference product. The research explores different diffusion models, emphasizing globally generated corrosion patterns. The outcomes include the creation of a synthetic dataset, the development of an accurate wear classification model, and a validated framework for integrating AI-based inspections in remanufacturing operations. This approach aims to improve efficiency and quality in remanufacturing processes, contributing to a circular economy.

Keywords: Remanufacturing, Machine Learning, Circular Economy

End-of-life decision-making in circular manufacturing: A Complex adaptive system of systems perspective (ID 81)

Tanver Hazari (NTNU)*; Carla S.A. Assuad (NTNU)

Abstract. End-of-life (EoL) decision-making in circular manufacturing is a critical challenge for sustainable industry. Traditional linear models fail to capture the dynamic and emergent behaviors of modern production systems. This paper develops a novel framework combining Complex Adaptive Systems (CAS) and System-of-Systems (SoS) perspectives to enhance EoL strategies such as reuse, remanufacturing, and recycling. Methodologically we com-bine CAS principle – adaptive system, self-organizing agents and nonlinear dynamics - with SoS principle which addresses interdependence among pro-duction networks, supply chains, and markets. The proposed framework of-fers practical decision support for optimizing resource recovery, reducing waste, and designing adaptive circular supply chains.

Keywords: End-of-life management, circular manufacturing, Complex adaptive system of systems.

End-of-Life Calculator: Aircraft Seat Case Study (ID 159)

Marco Franchino (AMRC)*; Cansu Kandemir (AMRC (University of Sheffield)); Christopher Haynes (AMRC (University of Sheffield)); Matteo Zamarco (AMRC (University of Sheffield))

Abstract. Manufacturing has traditionally prioritised cost, lead times, and quality over sustainability. However, increasing awareness of environmental impact demands greater accountability. The concept of sustainability often lacks clarity, and companies struggle to prioritise environmental goals.

This paper presents the development of an end-of-life (EoL) calculator based on selected key performance indicators (KPIs), divided into three areas— economic, environmental, and social—to evaluate EoL options such as disposal, recyclability, and raw material recovery, providing performance scores to support decision-making. This study includes a proof-of-concept case focused on the aviation sector, where non-operational factors contribute significantly to its carbon footprint. Aircraft cabin components, making up 10% of an airliner's empty weight and replaced multiple times during an aircraft's lifespan, create substantial waste, a significant portion of which is not recycled.

To validate the calculator, a Discrete Event Simulation (DES) model of the supply chain was developed to assess the recyclability of aircraft seats. This study highlights the challenges and opportunities of implementing circular economy practices in regulated sectors like aerospace.

Despite limitations, the calculator offers valuable insights and a foundation for sustainable manufacturing and supply chains. Future research should integrate advanced simulation techniques with emerging technologies to develop scalable circular solutions.

Keywords: Circular Economy, Decision-Making, Aerospace.

Sustainability Assessment of End-of-Life Strategies for PEM Fuel Cells
(ID 23)

Sophie Victoria Bernard (Bochum University of Applied Sciences); Erik Alexander Recklies (Bochum University of Applied Sciences)*; Semih Severengiz (Bochum University of Applied Sciences)

Abstract. Green hydrogen technologies play a significant role in the transition towards clean energy systems and the achievement of global climate goals. In particular, PEM fuel cells offer a variety of potential applications in domains such as transport and energy supply. However, PEM fuel cells contain many valuable resources and materials with non-negligible ecological impacts (e.g., platinum group metals, Nafion). There is a lack of a systematic analysis for evaluating and selecting End-of-Life strategies for PEM fuel cells considering sustainability criteria. This paper aims to contribute to filling this gap and is funded by the German Ministry of Environment as part of the project “GH2GH – Green Hydrogen for Sub-Saharan Africa”. The analysis is based on an extensive literature review and interviews with experts from research, politics, and industry. Different End-ofLife strategies for PEM fuel cells are presented focusing on applicability and feasibility. In this context, several R-strategies (Repair, Reuse, Recycle, and Recover) are considered. Additionally, possible criteria for a sustainability assessment of these End-of-Life strategies are elaborated and discussed.

Keywords: PEM fuel cell, Hydrogen technology, Circular economy, R-strategies.

Recovery of NdFeB Magnets from the Ferrous Fraction of Shredded Waste Streams by Physical Sorting
(ID 1)

Thorsten Ihne (Friedrich-Alexander-Universität, Institute for Factory Automation and Production Systemslangen-Nürnberg, Institute for)*

Abstract. A secure and sustainable supply of critical raw materials is crucial to the economic strategy of industrialized countries. In the context of the current transition to green technologies, this applies in particular to rare earth elements (REEs) used for neodymium-iron-boron (NdFeB) magnets, which are essential for various key applications. The European Union and the United States have classified these elements as critical because they combine significant economic relevance, poor substitutability and high supply vulnerability. Recycling can reduce dependency, but the necessary technical and organizational conditions are currently not given. Consequently, political, scientific and industrial stakeholders are intensifying their efforts to establish an effective circular economy. At least on a laboratory scale, a broad spectrum of methods for processing end-of-life (EOL) magnets exists, but magnet extraction is also a major challenge. For specific applications, dismantling or hydrogen processing are effective, but for sufficient processing capacities, the implementation of a universally applicable process based on shredding and subsequent sorting is essential. Therefore, the present paper discusses a multi-stage sorting approach for the ferrous shredder fraction using simulative and experimental investigations to fill the gap in the existing process chain. The focus is set on physical processes exploiting differences in the magnetic and mechanical properties of the relevant materials.

Keywords: Rare Earth Magnets; Critical Raw Materials; Recycling; Physical Sorting; Magnetic separation, Hard And Soft Magnetic Materials

Paper Session 8: Manufacturing Processes
Wed, 10th September - 16:30 - 18:30

Aula Magna

Data-driven energy consumption modeling of injection molding machine modules (ID 33)

Thorvald Alrø Martiny (Aarhus University); Ahmad Rami Mansour (Aarhus University); Devarajan Ramanujan (Technical University of Denmark)*

Abstract. Energy-efficient manufacturing has become a central focus in the industry due to sustainability concerns and supply volatilities. Due to their energy intensity and large-scale use, injection molding machines (IMMs) account for a significant share of global manufacturing energy consumption. Existing models for IMM energy estimation primarily focus on individual machines, making model scalability difficult in cases where manufacturers use diverse machine types. This paper presents a data-driven approach to modeling energy consumption for IMM modules (i.e., a collection of IMMs in a production facility), incorporating auxiliary systems such as heating, cooling, drying, and ventilation. Using production data from a large-scale manufacturer, we identify the minimum set of production variables needed for accurate energy consumption modeling. Key variables include the number of machines, machine size, type, and throughput. These variables were used to train random forestbased machine learning models to estimate the energy consumption of 3 separate IMM modules. Results show an average R 2 value of 0.95, 0.94, and −0.63 for energy consumption models trained with 80%, 20%, and 0% module-specific data, respectively. Our findings suggest that while the significance of production variables remains consistent across IMM module types, module-specific training data is required for accurate energy consumption estimation.

Keywords: Injection Molding, Energy Consumption, Machine Learning, Random Forest

INFLUENCE OF PROCESS PARAMETER VARIATION IN TURNING PROCESSES ON THE LIFE CYCLE ASSESSSMENT (ID 102)

Ralf Schlosser (Jade University of Applied Science)*; Knut Partes (Jade University of Applied Science)

Abstract. Machining processes, particularly cutting operations with defined cutting edges, are foundational to modern manufacturing due to their widespread application across various industries. However, assessing their ecological footprint presents significant challenges, especially within the framework of environmental life cycle assessments as established by DIN EN ISO 14040 ff. These challenges are primarily attributable to inherent uncertainties in existing models and life cycle inventory data sets that quantify the environmental impact of machining processes. This paper aims to address these uncertainties by conducting a detailed investigation into the energy consumption and tool wear associated with a modern DMG T1 turning machine. Through process-specific monitoring, essential data that informs a more accurate environmental assessment were captured.

The Life Cycle Assessment is modeled within the GaBi Software. By employing this standard software, we ensure the generation of results that are comparable within the state-of-the-art impact categories, such as Global Warming Potential, Acidification Potential, and Abiotic Depletion Potential.

The study also involves a meticulous comparison between external energy intake data and machine internal measurements to critically analyze discrepancies and underlying causes. By scrutinizing the results, the research contributes to refining the models used for the ecological assessment of cutting processes, promoting more sustainable manufacturing practices. The findings are anticipated to guide policy-makers, engineers, and researchers in optimizing machining processes for enhanced environmental performance, aligning with sustainable development goals.

Keywords: LCA, Machining, Universal CNC Lathe

Sustainability Index-Based Characterization of Al 3003 part in Die-Press versus Incremental Sheet Forming (ID 112)

Alejandro Simoncelli (INTI)*; Giampaolo Campana (UniBo); Leopoldo De Bernardez (ITBA); Luciano Buglioni (INTI); Antonio Sánchez Egea (UPC); Martín Gadaleta (Industrias MARO); Daniel Martinez Krahmer (INTI)

Abstract. Incremental Sheet forming (ISF) has become a sustainable alternative to traditional press stamping, particularly for small-batch production, complex geometries, and prototyping. By utilizing a localized deformation process, IF eliminates the need for large-scale dies and high-forming forces, reducing material waste and energy consumption in small-batch production with simpler tools. These attributes position ISF as an ideal choice for sustainable manufacturing practices in the medical, aerospace, and automotive industries. This study evaluates the performance of aluminum parts manufactured using traditional stamping and ISF. Tensile specimens were tested to assess mechanical properties. Additionally, the Consumption Performance Sustainability Index was calculated. The index includes sustainability aspects and the mechanical properties of the manufactured parts and is useful to characterize both forming processes. The results provide valuable insights for improving the efficiency and environmental performance of manufacturing processes.

Keywords: Sustainable Manufacturing, Consumption Performance Sustainability Index, Incremental Forming, Aluminum AA3003, Finite Element Simulation

Dual-Robot Wiring for High-Speed Control Cabinet Assembly (ID 158)

Milan Brisse (Ruhr-Universität Bochum Chair of Production Systems)*; Elias Milloch (Ruhr-Universität Bochum Chair of Production Systems); Bernd Kuhlenkötter (Ruhr-Universität Bochum Chair of Production Systems)

Abstract. The growing demand for control cabinets in energy infrastructure, such as electrolyzers, wind turbines, and charging stations, is hindered by a shortage of skilled workers, slowing down production. Wiring accounts for the largest share of process time in control cabinet assembly. Despite its potential, no turnkey solution exists for fully automated wiring due to the challenges of handling flexible components in cluttered spaces with complex collision geometries. This paper introduces a high-speed automation approach using two synchronized industrial robots with visual and force-sensitive sensors. By distributing tasks between the robots, process stability is increased while eliminating the need for complex gripper mechanisms. This simplification enables reliable wire handling and supports rule-based path planning for deterministic and repeatable wiring operations. The results demonstrate that coordinated robotic handling with force-sensitive control enables a fast, robust, and scalable alternative to manual wiring, advancing automation in control cabinet manufacturing.

Keywords: Renewable energy infrastructure, automated wiring, manufacturing tools, dual robot wiring

Harvesting Nature's Red Gold: An Environmental Assessment of Lycopene Conventional Extraction (ID 51)

Ana Pinzon (Fraunhofer IPA)*; Yannick Baumgarten (Fraunhofer IPA); Jennifer Kendler (Fraunhofer IPA); Surya Maechtlen (Fraunhofer IPA); Maximilian Schutzbach (Fraunhofer IPA); Robert Miehe (Fraunhofer IPA); Alexander Sauer (Fraunhofer IPA)

Abstract. Lycopene is a red tetraterpenoid-carotenoid pigment in fruits and vegetables, highly available in tomatoes, and has a lipophilic nature, i.e., insoluble in water. A unique feature of this carotenoid is that it allows for various applications, such as nutritional supplements due to its antioxidant properties, age-defying treatments, and a natural red colorant for food and beverages. Its advantages result in an expanded global market size, expected to be around USD 200 million by 2032. The environmental impacts of conventional lycopene extraction from tomato by-products are investigated with a life cycle assessment. The Environmental Footprint method, developed by the European Commission, is applied to calculate the impact categories for the process. Various scenarios and extraction methods are considered to assess the impact of different variables and identify hotspots. The electricity source is a hotspot on the laboratory scale. Otherwise, the solvents used for the extraction have the most significant environmental impact. Therefore, methods involving solvents are the most harmful. Some measures to reduce the environmental impact include recycling solvents or using other low-carbon substances for the extraction.

Keywords: Lycopene, conventional extraction, life cycle assessment.

Paper Session 9: Green Energy Systems
Wed, 10th September - 16:30 - 18:30

Aula B

Characterization of the Calendering Process for Sulfide-Based Solid-Electrolyte Separators (ID 108)

Johannes Schachtl (Technical University of Munich, TUM School of Engineering and Design, Institute for Machine Tools and Industrial Management; TUMint.Energy Research GmbH)*; Lovis Wach (Technical University of Munich, TUM School of Engineering and Design, Institute for Machine Tools and Industrial Management; TUMint.Energy Research GmbH); Elena Jaimez Farnham (Technical University of Munich, TUM School of Engineering and Design, Institute for Machine Tools and Industrial Management; TUMint.Energy Research GmbH); Rüdiger Daub (Technical University of Munich, TUM School of Engineering and Design, Institute for Machine Tools and Industrial Management; Fraunhofer Institute for Casting, Composite and Processing Technology IGCV)

Abstract. Industrializing solid-state batteries is crucial for advancing energy storage technologies as solid-state batteries offer a promising alternative to conventional lithium-ion batteries with increased energy densities and improved safety. Reducing the porosity and enhancing the particle-to-particle contact between particles of the solid-electrolyte separator has been shown to improve the performance of solid-state batteries. This study investigates calendering as a scalable process to achieve a homogeneous densification of solid-electrolyte separators. The influence of key process parameters on the solid-electrolyte separator's properties was examined using a pilot-scale calender for the processing of both sheet-based and coil-based materials. Interactions between the parameters and the resulting microstructural, mechanical, and electrochemical properties of the solid-electrolyte separators were analyzed. The findings of this work demonstrate that calendering significantly reduces the porosity of solid-electrolyte separators, creating mechanically robust, flexible free-standing separators. This enables rollto-roll processing and thus provides a scalable alternative to the predominantly used uniaxial pressing technique for producing solid-electrolyte separators.

Keywords: Solid-state battery, Calendering, Battery production

Development of sustainable aluminium foam components infiltrated with paraffin for battery housings (ID 98)

Rico Schmerler (Fraunhofer IWU)*; Welf-Guntram Drossel (Fraunhofer IWU); Thomas Hipke (Fraunhofer IWU); Rafael Wertheim (Braude Collage)

Abstract. Improved sustainability of car components like battery housings can be achieved using lightweight designs and infiltrated aluminium foam, providing high mechanical energy absorption and damping properties. Furthermore, their mechanical properties as well as the thermal conductivity and resistivity are much higher than polymer foams. Investigations were carried out on structures containing paraffin, a phase change material (PCM), infiltrated into the highly thermally conductive aluminium foam. Unique manufacturing processes and infiltration methods were developed and tested. The state-of-the-art for infiltration of aluminium foam with PCM was extended by two infiltration methods, enabling higher infiltration rates, increasing the effective thermal conductivity. Simulations regarding heat distribution and vibration properties were performed and validated by experimental investigations on component level. Variation of properties for multi-functional components can be designed through foam density and PCM. The sustainable composite solution is recommended for applications requiring both mechanical and thermal beneficial properties, such as battery housing floor components.

Keywords: Lightweight design, aluminium foam, phase change material, sustainability

Optimised and skill-based task allocation for the hybrid assembly of a water electrolyser in a human-robot interaction cell
(ID 44)

Lennart Lamers (RIF Institut für Forschung und Transfer e.V.)*; Lorenz Pietsch (Ruhr-Universität Bochum); Idris Yorgun (RIF Institut für Forschung und Transfer e.V.); Lukas Christ (Lehrstuhl für Produktionssysteme); Bernd Kuhlenkötter (Lehrstuhl für Produktionssysteme)

Abstract. The increasing demand for green hydrogen necessitates scalable and efficient production methods. It will be generated from sustainable energy to serve as a replacement for fossil fuels. Consequently, the demand for electrolyzers is increasing, necessitating faster production processes. Water electrolysers play a crucial role in this transition, yet their assembly remains predominantly manual, leading to high costs and inefficiencies. This paper presents an optimized hybrid assembly process for water electrolysers in a human-robot interaction cell. The technical boundary conditions were analyzed, and key target criteria—ergonomics, quality, and process time—were defined. A skill-oriented allocation of assembly tasks was developed to leverage the respective strengths of humans and robots. Process times were determined using MTM-UAS for human tasks and a specially developed Robot-PMTS method for robotic operations. Based on these findings, an optimized assembly sequence was derived, reducing physical strain on workers, ensuring high-quality standards, and minimizing throughput time. A standardized work plan was created to facilitate practical implementation. The proposed approach was validated through simulation, confirming its feasibility and effectiveness. The results provide a scalable, ergonomic, and cost-efficient assembly concept for the industrialized production of water electrolysers.

Keywords: Hybrid Assembly, Skill-based task allocation, Hydrogen, humanrobot coexistence, process optimization, water electrolyzer, sustainable production.

Social acceptance of green hydrogen in decentralized energy system - a case study of Ghana
(ID 91)

Emmanuel Effah (Bochum University of Applied Sciences); Erik Alexander Recklies (Bochum University of Applied Sciences); Severengiz Semih (Bochum University of Applied Sciences)*

Abstract. The transition toward renewable energy and the need for sustainable, reliable electricity in decentralized energy systems requires innovative solutions for long-term energy storage. Seasonal storage technologies, particularly hydrogen storage, offer advantages over battery storage, including enhanced durability and capacity for off-grid systems.
The goal of this research is to assess the adoption/acceptance perspective of the integration of hydrogen storage in a solar mini-grid at a pilot site in Tema, Ghana. This pilot project combines an electrolyzer for hydrogen production with hydrogen storage and fuel cell technology for the re-electrification of hydrogen, enabling self-sufficiency during periods of low solar radiation and eliminating the environmental harm associated with diesel generators.
This study will combine online data collection and in-person surveys at the pilot site to evaluate the acceptance of green hydrogen in a decentralized energy system across five key dimensions: community, socio-political, market, behavioural and attitudinal acceptance. Each dimension will be examined with selected indicators, considering local conditions.
The study will identify key factors influencing the adoption of green hydrogen in decentralized energy systems, providing insights to support policy development and scalability.

Keywords: Green hydrogen technologies, Social acceptance, decentralized energy systems.

Higher Sustainability For Energy Systems And Business Models: The Role Of Harmonic Mitigation For The Use Of Green Electricity
(ID 9)

Benjamin Jacobsen (Technische Universität Chemnitz)*

Abstract. To reduce the carbon footprint, improve manufacturing sustainability, and enhance energy efficiency, a reliable, efficient, and sustainable energy system is essential. A key objective of the German energy system is the efficient transmission and distribution of renewable electricity, reinforced by regulatory requirements. However, incentives to improve transmission efficiency, especially minimizing energy losses, remain insufficient. Power quality, particularly harmonics, plays a crucial role in this context. This study examines how harmonics affect energy efficiency. Prior research shows that mitigating harmonics can reduce energy losses, benefiting both the economy and manufacturing processes reliant on electrical energy. This paper quantifies potential energy savings for businesses by reducing harmonic-induced power losses. These savings are monetarily quantified, translating directly into lower grid usage fees, enhancing sustainability and business models. The study also explores approaches for harmonic mitigation within regulated electricity markets, identifying necessary regulatory adjustments for sustainability. The core contribution is calculating the reduction in primary energy demand resulting from such measures, reducing the carbon footprint and improving manufacturing sustainability. Based on these findings, the paper proposes a sustainable business model developed using Jacobsen's integrated methodology for regulated markets, advancing the sustainable energy transition and development.

Keywords: Sustainable Power Quality, Harmonic Mitigation in Manufacturing Systems, Energy Efficiency in Smart Grids, Regulatory Frameworks for Industrial Energy Use, Performance Metrics for Sustainable Manufacturing

Thursday, 11th September - 11:00 - 13:00			
Paper Session 10 Student Session I	**Paper Session 11 Design for Circularity**	**Paper Session 12 Artificial Intelligence**	**Paper Session 13 Factory Planning**
Municipal Waste Management in a Circular Economy	Knowledge Gaps in Circular Product Development: A Systematic Literature Review of the Manufacturing Industry (ID 166)	Application of generative AI in Industry 5.0: An SME case study (ID 188)	Ecologically interlinked manufacturing districts – a method for generating local synergies to increase sustainable value creation (ID 92)
The effects of customer base Scope 3 targets on suppliers' greenhouse gas emissions	Product Generation Interoperability to Enable Circular Economy in Product Development (ID 174)	Implementing Artificial Intelligence to Enhance Sustainable Value Creation of Palm Date Supply Chain: Case Study of Palestine (ID 5)	Technical and organisational readiness framework for facilitating development of sustainable manufacturing processes by urban and creative factories (ID 145)
Development of a Chatbot for ESG reporting for micro, small and medium-scale enterprises.	Integrating circular strategies into the development of complex systems by assisted subcontext modeling (ID 117)	The resource friendly experiment agent (ID 58)	A KPI-Based Approach to Evaluating Sustainable Land Use and Adaptable Infrastructure in Industrial Production Sites (ID 31)
Circular Economy Gamification for Industrial Contexts	Supporting Circularity Strategies by Integrating Sustain ability Aspects in SysML Models (ID 143)	The path towards a more efficient circular economy by integrating deep learning into robotic sorting systems (ID 30)	Impact Assessment of Digitalization: Cost and Environmental Aspects Using the Example of Digital Factory Initiatives (ID 105)
Closing the Loop: Recovering Value from End-of-Use Polyurethane Screens for Circular Economy	Unveiling Barriers to Recycling with a Focus on Design: An Ishikawa Diagram-Based Approach with Industrial Application (ID 181)	Sustainable Wax Form-Finding: AI-Assisted Robotic Arm System for Efficient Shape Manufacturing (ID 163)	Energy Flexibility as a Factory Design Parameter (ID 6)
Investigating the Upcycling of Aluminum Scrap Through Additive Friction Stir Deposition and Sheer Assisted Processing and Extrusion	A framework for Industry 4.0 implementation in circular aerospace manufacture (ID 118)	Framework and development of an AI-based application to support object recognition and consumer waste management (ID 17)	Towards a more sustainable manufacturing environment: A proposal on SDG-based design guidelines for planning an assembly line (ID 106)

Paper Session 10: Student Session I
Thursday, 11th September - 11:00 - 13:00

Aula C

Municipal Waste Management in a Circular Economy

Peter Thornton, Asela K. Kulatunga
University of Exeter

Abstract. Municipal waste management has become a growing issue worldwide, contributing to pollution and climate change. These have been increasingly affected by a rising population, urbanisation, an increasing consumption of goods and increased resource scarcity. While Municipalities and Local Authorities have inadequate and outdated waste infrastructure, and other barriers to contend with. Over the last few years, national Governments have started to introduce plans, strategies and
regulations to change the current linear system into a circular system. With targets from the UK Government approaching in 2035, there are some Local Authorities in the UK who are far from the target, including authorities in Devon.
The report aims to identify inefficiencies and barriers in the current linear system at a local level, in Devon, looking at how they could be addressed, and proposing solutions which could be applied locally and holistically to the UK, making the system more circular. It has collected publicly available secondary data from Governments and other sources, using it to analysis and compare the UK to a range of other countries. With the outcomes of this report being recommendations to local authorities and the UK government, with potential solutions which could be implemented to improve the circular economy.

Keywords: Waste Management, Circular Economy, Sustainability, Municipal Solid Waste

The effects of customer base Scope 3 targets on suppliers' greenhouse gas emissions

Leticia Canal Vieira, Natalia Cardenà, Mariolina Longo and Matteo Mura
University of Bologna, Italy

Abstract. This study investigates the impact of companies' Scope 3 targets adoption on suppliers' emissions. Drawing on signalling and social network theories, the study hy- pothesises that customers' adoption of a Scope 3 target signals suppliers to reduce carbon emissions and that the suppliers' network centrality moderates this effect. A panel dataset comprising 2436 dyads between suppliers and their customer networks over a five-year period has been developed. The analysis uses a random-effects panel regression model to test the hypotheses. Results indicate that suppliers connected to customers with Scope 3 targets report significantly lower emissions. Additionally, lower supplier access to the network and lower customers' structural influence attenuate the effectiveness of custom- ers' signals.

Keywords: Decarbonisation targets, signalling theory, Network Analysis.

Development of a Chatbot for ESG reporting for micro, small and medium-scale enterprises.

Tejas Suresh Bane and Teja Raghu Varma Alluri, Maxim Mintchev
Technische Universität Berlin, Geramany

Abstract. With the Implementation of the Corporate Sustainability Reporting di- rectives and the European Sustainability Reporting Standards (ESRS), micro, small, and medium-scale (SME) industries face a dilemma. Increasing demands from partners or clients, who are subject to mandatory reporting standards, have heightened indirect pressure on these businesses to disclose their sustainability practices. However, SMEs find it challenging because they often lack the exper- tise, resources and clarity to what to report and how. In response to this gap, our study presents the development of a user-friendly Chatbot to assist the MSME's in navigating through the Voluntary Sustainability Reporting Standards for the Non-Listed SME's (VSME) metrics, issued by EFRAG. This study examines the importance of sustainability practices and disclosures and explores how en- terprises can position themselves competitively by highlighting their sustainable initiatives. The chatbot, built using the Bot press platform and driven by a natural language (NLP) framework, simplifies the complex reporting requirements into conversational guidance. It offers step-by-step support in understanding key per- formance indicators (KPI's) and aligning with ESG expectations. This paper out- lines the regulatory background, identifies the practical obstacles the SME's face and how this intelligent conversational tool simplify access to sustainability re- porting and practices. The result revels a promising outcome for digital sustaina- bility reporting and emphasizes on scalable ESG adoption across Europe's MSME's sectors.

Keywords: Chatbot, Voluntary standard for non-listed small- and medium-sized enterprises (VSME), Environmental Social & Governance (ESG), CSRD, ESRS, Natural Language Processing (NLP)

Circular Economy Gamification for Industrial Contexts

Caitlin Vinopal, Hasret Sümeyye Uyan, Mohammed Aslam Hajanajubudeen, Felix von Amelunxen and Valentin Eingartner
Technische Universität Berlin, Germany

Abstract. Current linear take-make-waste manufacturing models have been shown to be unsustainable long term, leading to significant waste, depletion of water bodies, and reduction in ecosystems. This has led to the adoption of strat- egies, such as Circular Economy (CE), to ensure both the availability of resources and financial viability for the future. The CE-Hub Berlin aims to address the dis- crepancy in CE competency, particularly within Berlin's industrial infrastructure and its predominantly Small and Medium-sized Enterprises (SMEs), where im- plementation is constrained by limited stakeholder expertise. This project, devel- oped in collaboration with CE-Hub Berlin, addresses these barriers by creating an interactive, web-based game designed to transfer knowledge from an indus- trial and manufacturing perspective. Increasing interest and knowledge in circu- larity will increase implementation, creating more sustainable and robust manu- facturing for the future.

Keywords: Circular Economy, Competence Building, Gamification

Closing the Loop: Recovering Value from End-of-Use Polyurethane Screens for Circular Economy

Tamm Omar, Dhanraj Kharal, Mahsen Salah Al-Ani, Fazleena Badurdeen, I.S. Jawahir
University of Kentucky, USA

Abstract. Polyurethane (PU) is a widely used polymer in mining and aggregation industries due to its excellent mechanical and chemical properties. In the United States alone, thousands of kilotons of PU enter into waste streams each year, yet only small percentage is recycled and returned to the market, raising critical environmental and human health concerns. One US-based mining company, for example, discards approximately 6,000 end-of-use (EoU) PU screening panels annually, totaling around 50 tons of landfill waste. Despite its functional efficacy, these panels are discarded at the EoU generating enormous industrial waste as PU cannot be remelted or recast. To address this issue, this paper explores circular strategies for repurposing these discarded PU panels to extend their life cycle and reduce waste. It offers insight into how EoU products from one industry can be effectively adapted for applications in another sector, supported by relevant analysis. Ultimately, this work supports the circular economy (CE) by mitigating environmental impacts, preserving resources, and proposing an economically viable repurposing business model.

Keywords: Polyurethane, Circular Economy, End-of-Use (EoU), Value Recovery

Investigating the Upcycling of Aluminum Scrap Through Additive Friction Stir Deposition and Sheer Assisted Processing and Extrusion

Alan Hensley, Naser Alqseer, Lillian Melton, R. Sarvesha, James Caudill, Fazleena Badurdeen, I. S. Jawahir
University of Kentucky

Abstract. The increasing demand for sustainable manufacturing has prompted the development of innovative approaches to upcycle and more effectively utilize recovered materials for sustainable value creation. This study involves two solid-state processes, Friction Extrusion (FE) and Additive Friction Stir Deposition (AFSD), for producing deposits from post-consumer aluminum waste, specifically discarded single-use trays and lids, which can subsequently be utilized in the creation of new aluminum products.
The mechanical performance of this upcycling method is evaluated to establish a foundation for future research to facilitate Circular Economy (CE) with sustainability benefits. Recovered material is processed through this hybrid approach to demonstrate the feasibility of this approach for solid-state upcycling. Metal powders are incorporated to assess the alloying capability of this method. The mechanical properties of both the as-recovered and processed materials are investigated through metallographic analysis to evaluate the change in material characteristics throughout the method. The goal of this method, as an alternative to the traditional melting-based recycling, is to improve material efficiency and reduce energy consumption by avoiding remelting of recovered materials and addressing efficiency losses associated with existing solid-state recycling processes. This approach has the potential to lower energy usage and minimize waste throughout the recycling pathway, thereby aligning with CE principles by enabling the reintegration of scrap/waste and recovered materials from end-of-life (EoL) products into the value chain as higher-value products.

Keywords: Sustainable Manufacturing, Upcycling, Circular Economy

Paper Session 11: Design for Circularity
Thursday, 11th September - 11:00 - 13:00

Aula A

Knowledge Gaps in Circular Product Development: A Systematic Literature Review of the Manufacturing Industry (ID 166)

Jan Luca Twardzik (Fraunhofer IEM)*; Lynn Humpert (Fraunhofer IEM); Gerrit Cichon (Fraunhofer IEM); Roman Dumitrescu (Paderborn University)

Abstract. The linear economy's "take-make-waste" model causes severe environmental harm, especially in manufacturing – one of the most resource- and energy-intensive sectors. A circular economy offers an alternative, focusing on resource efficiency through reuse, recycling, and design for longevity. As up to 80% of a product's environmental impact is determined during development, this phase is a critical leverage point for circular implementation. Despite growing recognition of circular design principles, a key barrier is the lack of specific knowledge in product development to shift from linear to circular products. While prior research highlights the existence of this knowledge gap, its precise nature and impact remain unclear, hindering effective implementation. To address this gap – and considering the environmental relevance of manufacturing and the central role of product development as a leverage point – this systematic literature review analyzes existing studies on circular product development to identify and categorize knowledge gaps. Applying predefined selection criteria, the review reveals fundamental deficits. By systematically mapping these gaps, the study provides a structured foundation for future research and industrial strategies, enabling a more effective transition to circular product development.

Keywords: Circular Economy, Circular Product Development, Systems Engineering, Manufacturing Industry, Knowledge Gaps,.

Product Generation Interoperability to Enable Circular Economy in Product Development (ID 174)

Niels Demke (Helmut-Schmidt-University)*; Fabian Rusch (Helmut Schmidt University); Wilke Willems (Helmut Schmidt University); Jan Kostrzewa (Helmut Schmidt University); Frank Mantwill (Helmut Schmidt University)

Abstract. Achieving circularity in product development requires extending product lifespans through upgrades, reuse, and modular design. Industrial update factories provide a promising environment for implementing these strategies across multiple product generations. However, this entails significant complexity in anticipating future requirements, managing systemic changes, and supporting longterm design decisions. This paper proposes a structured approach to interoperability across product generations to support decision-making for circularity. By distinguishing between white box (past), grey box (in development), and black box (future) product generations, the framework serves as a transformation model, enabling a systematic analysis of generational interdependencies and resolving goal conflicts in a sustainable manner. Building on this, a scenario-based methodology is introduced to identify potential future influences, assess their relevance and criticality, and derive actionable design requirements in the early stages of current product development. The approach enhances anticipatory capabilities, reduces lifecycle-related risks, and promotes design flexibility by integrating cross-generational interoperability into product architectures. With this future-oriented decisions can be operationalized to extend product lifespans and increase circular value. Overall, the concept strengthens strategic planning capabilities in circular product development by formalizing generational interoperability as a design objective to support more resilient, resource-efficient, and future-ready products.

Keywords: Product Generations, Interoperability, Product Development.

Integrating circular strategies into the development of complex systems by assisted subcontext modeling (ID 117)

Fabian Rusch (Helmut Schmidt University)*; Veith Ihlow (Helmut Schmidt University); Valentin Schemmann (Helmut Schmidt University); Niels Demke (Helmut Schmidt University); Frank Mantwill (Helmut Schmidt University)

Abstract. The early integration of circular strategies into product development is crucial for contributing to a sustainable circular economy. Since complex product developments rely on modeling, it is reasonable to integrate circular strategies into these models. This integration, however, poses economic challenges due to the absence of modeling standards for non-linear lifecycles and the increased modeling effort required. This paper introduces a structured methodology for integrating circular strategies into Model-based Systems Engineering (MBSE) while reducing manual modeling efforts. The proposed methodology utilizes initial MBSE models tailored to specific circular strategy subcontexts. Semantic interoperability between the Systems Modeling Language (SysML) and Kernel Modeling Language (KerML) is used to provide a link to Large Language Models. Retrieval-Augmented Generation is then used to formalize recommendations for the subcontext model. These recommendations are provided to the developers via KerML within the SysML environment, assisting them to reduce the required manual effort for subcontext modeling. The evaluation of a subcontext expansion demonstrates a reduction in modeling effort and an increased information density while maintaining model consistency and quality. Furthermore, the iterative recommendation mechanism supports continuous model evolution, making this approach particularly valuable for implementing circular strategies in adaptive, iterative product development.

Keywords: Circular Strategies, Assisted Subcontext Modeling, Model-based Systems Engineering, Transformer Models, Retrieval-Augmented Generation.

Supporting Circularity Strategies by Integrating Sustain ability Aspects in SysML Models (ID 143)

Yannick Juresa (RPTU Kaiserslautern)*; Damun Mollahassani (RPTU Kaiserslautern); Jens C. Göbel (RPTU Kaiserslautern)

Abstract. Implementing sustainable and circular strategies for smart products requires consistent improvement of transparency and traceability over the entire product lifecycle. The early stages of product development play a critical role in the effective integration of sustainability strategies, as decisions made during this phase significantly influence the environmental performance throughout the product lifecycle. However, a consistent and direct assignment to system elements is a significant challenge. However, sustainability strategies such as reuse, remanufacturing, or reconfiguration require detailed models of (sub-)systems. To address these challenges, this paper focuses on a modeling approach that uses the Systems Modeling Language (SysML) v2 to model sustainability aspects at an early stage and links them to generic SysML v2 parts. For the instantiation, these generic blocks are linked to a complete set of system elements using the example of a 3D printer.

Keywords: Circular economy, Sustainability, Model-based Systems Engineering, SysML, Smart Products.

Unveiling Barriers to Recycling with a Focus on Design: An Ishikawa Diagram-Based Approach with Industrial Application
(ID 181)

Katharina Rohde (Paderborn University)*

Abstract. The circular economy offers decisive advantages over the currently prevalent linear economy in industry. Firstly, the reuse of products, individual parts and material reduces the need for new production or generation and the associated consumption of energy and resources. Secondly, it helps to avoid the generation of waste. Early consideration of circular economic principles in product development processes is essential to specifically promote reuse, reparability and recycling. Efficient recycling of assemblies requires well-defined strategies. However, various challenges hinder the efficiency of technical recycling processes in industrial applications. This paper presents an Ishikawa (fishbone) diagram-based approach to systematically identify and categorize these influences. The method is implemented within an industrial framework, highlighting key obstacles such as material composition, design constraints, use of technology, framework conditions, economic limitations and regulatory challenges. By applying a scenario analysis, this approach examines potential future developments and their impact on recycling-oriented design choices. This helps to identify critical influencing factors and supports the development of resilient and sustainable industrial practices. This framework will serve as the foundation for developing an automated approach to circular design, enabling industries to more effectively integrate sustainability into their processes and adapt to changing environmental demands.

Keywords: Recycling Barriers, Design for Recycling, Product Development, Eco-Design, Sustainable Product Design, Industrial Application.

A framework for Industry 4.0 implementation in circular aerospace manufacture
(ID 118)

Rylan Cox (Cranfield University)*; Yagmur Atescan (Cranfield University); Yousef Haddad (Cranfield University); Konstantinos Salonitis (Cranfield University)

Abstract. Aerospace manufacturing is at a critical turning point in transitioning to Sustainable Aviation Fuels (SAF), which will redirect environmental emission emphasis towards manufacturing. Significant amounts of aerospace structural components are made from aluminium or titanium alloys, contributing to the bulk of Greenhouse Gas (GHG) emissions from the manufacturing process. Due to the regulatory and mechanical properties of aerospace-grade alloys, strict recycling and material control are required to ensure the same grade is used for new parts, hence the reliance on virgin material. “Aircraft graveyards” are growing with a new fleet of aircraft being manufactured in the coming decades. Due to their untracked nature and a long, complex paper trail, identifying material types for recyclability into new planes is unfeasible. A strategy to move aerospace materials to the circular economy is critical in curbing the sector's GHG emissions. Industry 4.0 (I4.0) is vital in moving efficient, smart and sustainable manufacturing. At the fundamental level, I4.0 requires Internet of Things (IoT) sensors to collect and transmit data for a relevant function. This paper looks at implementing a framework for recording part manufacturing emissions, material type and processing to enhance recyclability by leveraging multiple aspects of I4.0, creating digital product passports.

Keywords: Aerospace, Digitalisation, Circular Economy, Industry 4.0.

Paper Session 12: Artificial Intelligence
Thursday, 11th September - 11:00 - 13:00

Aula Magna

Application of generative AI in Industry 5.0: An SME case study
(ID 188)

Tim van Erp (Flinders University)*; Bruno Pereira (Flinders University); Adela McMurray (Flinders University)

Abstract. Novel generative Artificial Intelligence (genAI) tools are increasingly being introduced to the marketplace, offering new opportunities for manufacturing companies. Often, Small and Medium-Sized Enterprises (SMEs) struggle to navigate the landscape of newly released software solutions due to a lack of AI competencies and limited resources for technology scouting. This qualitative research discusses a novel SME case study for combining multiple genAI tools to reduce the time-to-market of new products significantly. The case study covers ideation, computer-aided design (CAD), and computer-aided manufacturing (CAM) as relevant manufacturing phases for SMEs engaged in New Product Development. Based on the case study, a critical discussion of Industry 5.0 benefits and barriers to using genAI in manufacturing is presented. Ultimately, the research contributes to fostering a culture of innovation by demonstrating a novel combination of genAI tools to support the design-for-manufacturing process. This can significantly decrease the time-to-market and improve the return-on-investment, competitive advantage, and potentially a transition towards Industry 5.0 if the barriers to genAI adoption are overcome.

Keywords: Sustainable Manufacturing; New Product Development; Innovation

Implementing Artificial Intelligence to Enhance Sustainable Value Creation of Palm Date Supply Chain: Case Study of Palestine
(ID 5)

Ahmed Abu Hanieh (Birzeit University)*; Afif Hasan (Birzeit University)

Abstract. This research concentrates on involving modern Artificial Intelligence (AI) technologies in the different stages of palm date production in Palestine. Palm date farms are now increasing and accelerating to compete with olive sector as one of the most important income sources, knowing that olive sector was the main contributor in GDP in Palestine since a long time ago. This diversification in agricultural income helps in improving the Palestinian economy which is climbing slowly due to political volatile situation. These sectors suffer from many problems and obstacles related to high weakness in implementing modern agricultural technologies which influences the production's quality and quantity. Farmers in Palestine still use traditional means in cultivation and post-harvest industries. Using modern AI technologies is becoming a stringent need to improve production and increase the value creation of these products. Simulation shows that implementing AI techniques can double the added value increasing the value creation index from 1.4 to 2.3. To implement AI while enhancing sustainability, energy sources used in agricultural processes can be transferred into renewable ones, mainly solar energy. Using high efficiency Photovoltaic panels in irrigation and cultivation processes can enhance quality and productivity of dates significantly.

Keywords: Added Value, Artificial Intelligence, Palm Dates, Sustainability, Value Creation Index.

The resource friendly experiment agent
(ID 58)

Müller Enno (FraunhoferIPK)*

Abstract. Augmenting large language models (LLMs) with external tools has proven to be effective for producing consistent, deterministic results. While capabilities of agentic ai systems are growing rapidly and the integration into various domain application speeds up, their resource consumption finds little attention in literature. With continuously more capable models requiring more energy, coupled with ever increasing numbers of users, there is a need for alternative solutions. We present an approach of using small-scale open-source models locally powering an agentic ai system in the context of production planning. By defining and iteratively executing experiments, the system can optimize discreteevent simulation models – while running entirely on-device. With significant drawbacks in speed and performance, the local configuration consumes only a fraction of the estimated resources of state-of-the-art models. By offering further benefits in data sovereignty, operational independence and cost control, the concept of locally deployed models presents an attractive alternative for industrygrade manufacturing applications.

Keywords: Discrete Event Simulation, Agentic AI, Resource Consumption

The path towards a more efficient circular economy by integrating deep learning into robotic sorting systems
(ID 30)

Alexander Schlosser (Institute for Factory Automation and Production Systems, Friedrich-Alexander-Universität Erlangen-Nürnberg)*; Jonas Walter (Institute for Factory Automation and Production Systems, Friedrich-Alexander-Universität Erlangen-Nürnberg); Lukas Roming (Fraunhofer Institute of Optronics, System Technologies and Image Exploitation); Jörg Franke (Institute for Factory Automation and Production Systems, Friedrich-Alexander-Universität Erlangen-Nürnberg); Sebastian Reitelshöfer (Institute for Factory Automation and Production Systems, Friedrich-Alexander-Universität Erlangen-Nürnberg)

Abstract. The recycling process is a critical component of sustainable resource utilization. The heterogeneity of material flows poses a significant challenge to the automation of sorting processes.
Despite advances in automated recycling, achieving a high level of material purity remains challenging. The prevailing sorting technologies currently possess limited accuracy in recognizing and distinguishing similar materials and contaminants. The impact of sorting accuracy on recycling rates is a critical consideration in the field. The present study focuses on the accurate detection, classification, identification and segmentation of objects during the recycling process. The study demonstrates the potential of real-time segmentation models to enhance robotic sorting systems. By leveraging advanced deep and computer vision techniques, such systems possess considerable potential to enhance the detection and classification of objects, thereby optimizing the efficiency of recycling processes. However, their performance in real data sets indicates a need for improvement in their generalization to different and uncertain conditions in the real world. This allows for real-time image processing. The system also enables the integration of object recognition, segmentation, and robot control into automated sorting systems. The findings demonstrate the performance of contemporary segmentation models in recycling processes, exhibiting enhanced adaptability to real and unpredictable conditions.

Keywords: Recycling, Sorting, Automation.

Sustainable Wax Form-Finding: AI-Assisted Robotic Arm System for Efficient Shape Manufacturing
(ID 163)

Kheng Lim (Yuan Ze University)*

Abstract. This research introduces a sustainable wax form-finding system utilizing robotic arm control integrated with artificial intelligence (AI) gesture recognition technology. Traditional form-finding processes, often limited by unpredictability and high material waste, are enhanced by this innovative method combining intuitive gesture-based interactions and precise robotic controls. The developed system allows designers to remotely control wax material formation using intuitive hand gestures captured by AI image recognition, significantly reducing material waste, energy consumption, and production time compared to conventional 3D printing techniques. By precisely regulating temperature, rotation, and movement, the system achieves optimal balance between material fluidity and controlled shaping. Furthermore, wax as a recyclable phase-change material offers environmental benefits through repeated use in prototyping phases, aligning closely with sustainable manufacturing principles. Experimental results demonstrate improved predictability, efficiency, and substantial environmental advantages, showcasing the potential of integrating interdisciplinary technologies—robotics, AI, and sustainable materials—in contemporary product design and manufacturing processes.

Keywords: Sustainable Manufacturing, Phase Change Materials, AI Gesture Recognition, Wax Recycling, Form-Finding.

Framework and development of an AI-based application to support object recognition and consumer waste management
(ID 17)

Lisa Klatt (Ostfalia Hochschule für angewandte Wissenschaften)*; Klaus Bolze (Ostfalia Hochschule für angewandte Wissenschaften); Thomas Potempa (Ostfalia Hochschule für angewandte Wissenschaften); Max Patrick Ehleben (Ostfalia Hochschule für angewandte Wissenschaften)

Abstract. The recycling of waste materials plays a key role in conserving natural resources. To promote material circularity, it is necessary to consider all processes along the value chain, from raw material extraction to waste management and processing. Effective collection and sorting of end-of-life products and packaging are crucial prerequisites to achieve high recycling rates, minimize energy consumption and reduce material losses. However, a significant proportion of post-consumer waste is not properly returned to established waste management systems by consumers. To address this challenge, recent developments in AI-based object recognition can support citizens in the form of a mobile app. This type of application can assist users in identifying items and suggests the most effective local recycling pathways to facilitate waste separation by type. To raise these potentials, a framework is presented that combines two apps: one for consumers to optimize recycling routes and a second app for collecting data to train the AI models. A novel classification system was created, and data suitable for AI training were collected to ensure the effectiveness of the system. In future, this application can contribute to directing household material flows into specific recycling pathways. In this way, the application can strengthen the circular economy in Europe and support environmental protection efforts.

Keywords: AI-supported object recognition, recucling, circular economy, material flows.

Paper Session 13: Factory Planning
Thursday, 11th September - 11:00 - 13:00

Aula B

Ecologically interlinked manufacturing districts – a method for generating local synergies to increase sustainable value creation
(ID 92)

Michael Hertwig (Fraunhofer IAO)*; Jannik Munderich (University of Stuttgart); Adrian Barwasser (Fraunhofer Institute for Industrial Engineering IAO)

Abstract. The sustainable transition is being taken seriously by industries worldwide, but progress remains slower than anticipated. The primary challenge lies in the limited scope for holistic improvements due to economic hurdles and isolated decision-making within companies. Creating synergies between different industrial and municipal entities offers a promising solution. However, this complex process is often managed by municipal authorities without adequate tool support. To address this, we propose a methodological approach that simplifies the collection and processing of relevant data. Beyond gaining corporate buy-in, obtaining and analyzing company-specific data is crucial. A software-based tool has been developed to systematically identify, quantify, and visualize synergy potentials across different stakeholders. These insights enable the development of tailored, location-specific scenarios, providing a concrete roadmap for cross-organizational sustainable transformation. The necessary collaborative decision-making process—in which all relevant stakeholders should be involved—is facilitated through an interactive visualization tool. The additional benefits of the application will be outlined based on two illustrative examples.

Keywords: Sustainable Industrial district, urban production, sustainable value creation networks.

Technical and organisational readiness framework for facilitating development of sustainable manufacturing processes by urban and creative factories
(ID 145)

Fedoua Kasmi (Université de Lorraine); Michel Langhammer (Helmut-Schmidt-Universität/Universität der Bundeswehr Hamburg); Anaelle Hily (Université de Lorraine); Robert Mies (Technische Universität Berlin)*

Abstract. Urban factories integrate manufacturing into cities, supporting circular, local supply chains, creativity and collaborative production. However, despite their potential, they lack standardised methods to assess their readiness as manufacturing hubs. Existing models focus on large-scale industry, overlooking the constraints of these spaces within urban settings. Local Accessible Urban Digital and Sustainable (LAUDS) factories in the form of makerspaces, fab labs, and co-working manufacturing spaces offer digital fabrication tools as shared environments for commercial and creative value creation within educational, research, and community infrastructures. This paper presents a technical and organisational readiness framework that draws on literature combining sustainable urban manufacturing, Industry 5.0, and New European Bauhaus principles, as well as insights from workshops and surveys of eight case studies. The framework identifies key physical, digital, and organisational features essential for enabling effective small-batch production capabilities.

Keywords: Sustainable Urban Manufacturing, Infrastructure, Readiness.

A KPI-Based Approach to Evaluating Sustainable Land Use and Adaptable Infrastructure in Industrial Production Sites (ID 31)

Oskay Ozen (PTW | TU Darmstadt)*; Michael Frank (PTW | TU Darmstadt); Robin Zink (PTW | TU Darmstadt); Matthias Weigold (PTW | TU Darmstadt)

Abstract. To be able to keep up with future regulations, technologies, and sustainability goals, German companies are shifting their site planning approaches towards long-term flexibility through means such as adaptable factories, multi-use spaces and buildings, and a future-proof energy infrastructure. As part of the DELTA Energy Laboratory, a city level regulatory sandbox project in Darmstadt, transformation strategies for producing companies are being analyzed and implemented. To this end, KPIs were developed around a metalworking facility to evaluate land use and densification of localized production sites, based primarily on high-level information about the site. The five KPIs are: site area utilization, proportional and absolute floor space utilization, and proportional and absolute ground plan utilization. Considered building types include factories, energy utilities, office spaces, storage facilities, data centers, and roads, supplemented by additional site area used for green spaces, bodies of water, and social infrastructure. These KPIs were developed together with industry experts and can be used for an initial sustainability assessment of both individual factories and the encompassing production sites, to facilitate site transformations in line with company goals. The KPIs were successfully applied to a production site in the chemical industry.

Impact Assessment of Digitalization: Cost and Environmental Aspects Using the Example of Digital Factory Initiatives (ID 105)

Linda Becker (Bochum University of Applied Sciences)*; Timo Fleschutz-Balazero (HTW Berlin); Semih Severengiz (Bochum University of Applied Sciences)

Abstract. With IT contributing nearly 4% to global CO_2 emissions, it presents both risks and opportunities for achieving sustainability goals. While digital technologies can enhance resource efficiency, they also increase energy consumption and environmental costs. This paper presents a framework for evaluating the environmental impact of Digital Factory Initiatives in their early planning stages. The approach combines methods from Green IT and Life Cycle Assessment (LCA) to enable a structured comparison of digitalization alternatives. Since ecological assessments alone may overlook broader organizational concerns, the framework integrates sustain-ability criteria into existing economic evaluation systems, supporting decisions that are both environmentally and financially sound. The result is a framework for stakeholders in product management, manufacturing, and sustainability, helping them select digital solutions that balance performance, cost, and ecological impact.

Keywords: Digital Factory Initiatives, Green IT, Green IoT, TEI, BSC, Costs.

Energy Flexibility as a Factory Design Parameter
(ID 6)

Stefanie Samtleben (Fraunhofer IFF)*; kerim Torolsan (Fraunhofer IPA); Thomas Sobottka (Fraunhofer Austria)

Abstract. To raise the amount of renewable energy sources means to make the energy supply dependent on the weather. Therefore to guarantee a high supply quality the infrastructure must grow or be used smart. The smart operation of factories can help to increase the amount of renweable energy sources in the supply systems. Especially energy intensive companies could provide their energy flexibility, if they knew it.
In this context a new method to estimate the energy flexibility potential of different factory designs is provided. The estimation uses the residual load instead of a global price, that does not consider the capacities of the energy supply network. In this paper we show how to use the correlation between the residual load of the energy supply and the energy demand of the factory, named relocation coefficient, to dimension the production capacities.
By systematically examining different structures and production scenarios for an aluminum foundry, we were able to achieve and demonstrate optimization in the correlation between residual load and energy consumption. To finally compare the scenarios different energy supply cases were assumed and further performance indicators were considered, such as work in progress and lead time. This optimization signifies an enhancement in the utilization of renewable energy sources.

Keywords: energy flexibility, factory planning, optimization, production planning and control

Towards a more sustainable manufacturing environment: A proposal on SDG-based design guidelines for planning an assembly line
(ID 106)

Jonte Pietsch (TUHH - IFPT)*

Abstract. Manufacturing systems impact sustainable development among others through resource consumption and emissions, but also through working conditions and economic value creation. While planning and designing of production systems traditionally prioritizes economic efficiency, a more holistic approach incorporating environmental and social sustainability is needed. This research develops comprehensive design principles for a more sustainable assembly lines based on their potential contribution to key Sustainable Development Goals. Sustainability criteria are systematically transferred into a framework that supports practical implementation in a general planning process. The resulting framework provides specific guidance for both high-level planning and detailed planning phases of assembly systems. The developed principles are a first attempt to enable companies to balance economic requirements with environmental resource conservation and social considerations.

Keywords: SDGs, sustainability, sustainable manufacturing, circular economy, sustainability criteria, assembly line, manufacturing process.

Thursday, 11th September - 11:00 - 13:00			
Paper Session 14 **Student Session II**	**Paper Session 15** **Sustainable Product Design**	**Paper Session 16** **Safe and Sustainable by Design I**	**Paper Session 17** **Product Planning and Control I**
Ecodesign Approaches for Mechanical Component Development at the University of Bologna Motorsport Team	Sustainable and Efficient Design of Lightweight Suspension Components Using ANOVA and RSM (ID 69)	Towards Addressing Co-Creation Gaps: Automating Safe-and-Sustainable-by-Design Workflows with Electronic Lab Notebooks (ID 74)	Opportunity Costs in Production Full Cost Accounting: A Systematic Literature Review (ID 65)
Metal hydride test bench development for investigation of sustainable and efficient hydrogen storage	A BENCHMARKING ANALYSIS OF COMMERCIAL SOFTWARE FOR TOPOLOGY OPTIMIZATION IN INDUSTRIAL APPLICATIONS (ID 130)	Strengthening value chains through SSbD: Insights from the BIO-SUSHY project (ID 176)	An Analytical Framework for Literature Review on Application of Manufacturing Efficiency Methods for Environmental Impact Reduction in the Fashion Industry (ID 110)
Gap Analysis of Documentation Template for Open Source Hardware and Adoption in Documentation Workflows with Large Language Models	Digital Twin-Enabled Conversion of Spent Mushroom Substrate for Circular Bio-Based Material Manufacturing (ID 154)	Micro-engineered capsules: a powerful tool in green chemistry (ID 111)	Intralogistic Value Creation – Potential of mobile assembly processes (ID 40)
	Open Source Hardware in SMEs: An Empirical Analysis of Adoption, Challenges, and Sustainability Potential (ID 12)	Advancements in sustainable aqueous Zn-ion batteries via exploring new cathode & anode optimisation strategies (ID 116)	Energy and Emission Impact Assessment of Path Planning in Four-Way Shuttle-Based Storage Systems (ID 127)
	Balancing Sustainability and Safety: Reducing Greenhouse Gas Emissions in Medical Devices (ID 35)	Next-Generation Flame Retardant Additives: A Path Toward Sustainability and Safety (ID 133)	Enhancing Production Planning and Control by Integrating the Circular Strategy `Repair´ (ID 43)
		Calcium Ferrites: Innovative and Multifunctional Solutions for Wastewater Treatment (ID 4)	Towards Simulation-Driven Framework for Optimising Rail Depot Operations and Maintenance Scheduling (ID 160)

Paper Session 14: Student Session II
Thursday, 11th September - 14:00 - 16:00

Aula C

Ecodesign Approaches for Mechanical Component Development at the University of Bologna Motorsport Team

Noemi Gurieri, Emanuele Morelli, and Matteo Garulli
University of Bologna, Italy

Abstract. UniBo Motorsport is the official motorsport team of the University of Bologna that designs, builds, and tests high-performance competition prototypes (an electric mo- torbike and two cars - one hybrid and one driverless). At present, the team consists of a number of students, organised into ten departments and possessing interdisciplinary compe- tencies. The association enables students to increase their technical expertise, management skills, and teamwork capabilities through tutored teamwork. UniBo's Motorsport is achieving outstanding results, including a recent world championship title for its electric two-wheeled prototype. Despite these achievements, the transition to sustainable manufacturing remains a key challenge as the team strives to balance high performance with environmental responsi- bility, as this paper stands out. Thanks to the research conducted with the support of one of the team's sponsors, UniBo's Motorsport carried out a detailed analysis based on ISO 14067, focusing on the carbon footprint assessment of the steering wheel components, adopting the Life Cycle Assessment (LCA) method in accordance with ISO 14040 and ISO 14044. These standards have made it possible to define the requirements for an integrated Environmental Management System (EMS), primarily through the evaluation of manufacturing processes, identifying potential material modifications, optimising machining operations, and achieving improved design solutions for mechanical components.

Keywords: Ecodesign, LCA, Formula SAE, Carbon Footprint, Sustainable Manufacturing.

Metal hydride test bench development for investigation of sustainable and efficient hydrogen storage

Prof. Dr.-Ing. Clemens Biet, Sanjeev Kumar Sundara Raju, Ayush Chaturvedi, and Parasuram Mahadevan
Technische Universität Berlin, Germany

Abstract. This paper presents the development of a metal hydride test bench designed to investigate sustainable and efficient hydrogen storage technologies. The system utilizes LaNi5, a widely studied metal hydride with favorable absorption/desorption kinetics and stability. A thermo- dynamic simulation model is implemented alongside the physical setup to predict system behavior and support experimental design. The test bench includes pressure and temperature control systems, safety test- ing, and precise measurement instrumentation. This platform enables future testing of various hydride materials, including recycled or indus- trial waste-based alloys, supporting broader research efforts toward safe, low-energy hydrogen storage solutions.

Keywords: metal hydride, LaNi5, hydrogen, tank design, modelling

Gap Analysis of Documentation Template for Open Source Hardware and Adoption in Documentation Workflows with Large Language Models

Neeraj Chodankar*, Sagar Didaga Ramakrishna, Sejal More, Atharva Chitrakar, Julien Colomb, Robert Mies
Technische Universität Berlin

Abstract. Effective documentation is critical for the reproducibility and scalability of Open Source Hardware (OSH), yet widely used minimal templates often omit essential elements such as testing protocols, assembly instructions, and compliance metadata. To address this, we applied a two-phase approach that combined benchmarking a documentation template against seven OSH projects with testing Large Language Models (ChatGPT and Gemini AI) as Natural Language Processing (NLP) assistants. The goal was to evaluate template coverage, identify recurring gaps, and assess whether LLMs can automate documentation tasks such as detecting changes, prompting for missing information, and generating structured updates. Results show that while the template broadly covers essential categories, consistent adoption remains a challenge, and LLMs can reduce manual effort by ensuring cross-file consistency and flagging missing assets. This demonstrates a scalable pathway to improve OSH documentation quality, reproducibility, and long-term maintainability, while reducing the workload for developers and helping new contributors apply documentation templates more effectively.

Keywords: Open Source Hardware; Documentation Templates; Large Language Models; Natural Language Processing; Reproducibility

Paper Session 15: Sustainable Product Design
Thursday, 11th September - 14:00 - 16:00

Aula A

Sustainable and Efficient Design of Lightweight Suspension Components Using ANOVA and RSM
(ID 69)

Giulio Galie (Università di Bologna)*; Marco Freddi (Università di Bologna); Leonardo Frizziero (Università di Bologna)

Abstract. This paper investigates the optimization of a Formula SAE kart suspension system, focusing on rocker triangle geometry through a simulation-driven and resource-efficient design process. A series of mechanical simulations were conducted to analyze the vehicle's dynamic behavior under various conditions, including acceleration, braking, and cornering. The suspension geometry, specifically the spatial configuration of the three points defining the rocker triangle, was systematically varied. A response surface model (RSM) was then employed to identify the optimal configuration using analysis of variance (ANOVA). This approach enables the prediction and evaluation of component performance prior to detailed virtual modeling and subsequent physical fabrication, offering a more efficient alternative to conventional trial-and-error methods. The optimized configuration serves as a foundation for CAD development and further component testing. By streamlining and generalizing the design process at an early stage, this method not only reduces development time and cost but also minimizes resource consumption, contributing to a more sustainable and precise engineering solution.

Keywords: Response Surface Method; Vehicle Design; Sustainable Engineering Design; Suspension Geometry Optimization; Optimal Design.

A BENCHMARKING ANALYSIS OF COMMERCIAL SOFTWARE FOR TOPOLOGY OPTIMIZATION IN INDUSTRIAL APPLICATIONS
(ID 130)

Alessandro Ceruti (University of Bologna)*; Sara Mantovani (University of Modena and Reggio Emilia); Mauro Giacalone (University of Modena and Reggio Emilia)

Abstract. Topological Optimization and Generative Design are methodologies that can reduce the weight of aerospace and automotive components without worsening stiffness, strength, or natural frequency. The obtained shapes are typically based on complex geometries and can hardly be obtained using traditional working processes, such as chip removal machining; additive manufacturing technologies should be used instead. Several commercial tools are available to design lightweight structures, providing different results when optimization is performed to reduce mass while preserving stiffness or stress. In this paper, a case study is shown to support the wide variety of shapes that can be obtained, and an interview among experts in the field has been carried out to understand the motivations underlying the preference for an optimized model over another one. Those comments can be helpful for software developers to match the users' requests better and develop the new generation of CAD systems capable of handling lightweight complex shapes.

Keywords: lightweight structures, Additive Manufacturing, FEM analysis, aerospace, automotive.

Digital Twin-Enabled Conversion of Spent Mushroom Substrate for Circular Bio-Based Material Manufacturing (ID 154)

Yujia Luo (York St John University)*; Peter Ball (University of York)

Abstract. Digital Twin (DT) technology offers a transformative approach to converting spent mushroom substrate (SMS) into sustainable bio-based materials, addressing critical challenges in circular manufacturing. By integrating advanced data acquisition, virtual simulation, and process optimization, this research develops a comprehensive framework that transforms low-value agricultural waste into high-performance insulation and packaging materials through sensor networks and machine learning algorithms. The study, validated through a case study with AgriCycle Innovation Ltd, demonstrates the framework's potential by achieving significant performance improvements, including energy savings, reductions in waste disposal costs, and compliance with insulation performance standards. The approach facilitates proactive process adjustments, reduces experimental iterations, and supports energy-efficient scale-up across operational and sustainability objectives. Addressing key research questions on optimizing SMS conversion and enhancing supply chain management, the research provides a scalable and replicable model for agricultural bio-waste conversion. By showcasing how DT systems can underpin intelligent, adaptive, and resource-efficient manufacturing systems, the study accelerates the transition toward circular bio-based material production, aligning operational performance with sustainability and economic objectives.

Keywords: digital twin, spent mushroom substrate, circular manufacturing

Open Source Hardware in SMEs: An Empirical Analysis of Adoption, Challenges, and Sustainability Potential (ID 12)

Cäcilia Veliu (HTW Dresden)*; Maximilian Stange (Fraunhofer IWU); Dirk Reichelt (HTW Dresden); Steffen Ihlenfeldt (Fraunhofer IWU)

Abstract. Open Source Hardware (OSH) refers to the design and development of physical products whose specifications are freely available for study, modification, and distribution. OSH presents significant economic potential by enabling cost-effective innovation, fostering collaborative development, and providing tailored solutions for specific business needs. Beyond these advantages, OSH also contributes to sustainability by reducing resource consumption through reuse, adaptation, and further development of existing solutions. Especially small and mediumsized enterprises (SMEs) may benefit from OSH. We conducted a survey assessing the familiarity of SMEs with OSH, their interest in its adoption, and perceived barriers. The results offer critical insights into SMEs' awareness, attitudes, and preferred ways of engaging with OSH. While most respondents were familiar with open-source software, awareness of OSH remained comparatively low. However, after a brief introduction to OSH, the majority stated interest and a wanted to learn more about its potential. The findings underscore the broader relevance of OSH, identifying practical strategies to enhance awareness, adoption, and long-term engagement among SMEs. By embracing OSH, businesses can not only drive innovation and cost efficiency but also contribute to a more sustainable and resilient industrial landscape.

Keywords: Open Hardware, SMEs, Resource efficiency, (Open) innovation.

Balancing Sustainability and Safety: Reducing Greenhouse Gas Emissions in Medical Devices (ID 35)

Diana Völz (Frankfurt University of Applied Sciences)*; Maria Heckel (Frankfurt University of Applied Sciences); Julia Schneider (Frankfurt University of Applied Sciences)

Abstract. As part of a research project, a bio-based plastic is being developed as a substitute material for infusion bags. Infusion bags represent an example of a disposable product in the healthcare sector. The high volume of infusion bags utilized daily generates significant quantities of plastic waste and CO2 emissions. This highlights the motivation to replace these materials with a more environmentally friendly alternative. Studies indicate that bio-based plastics can be more sustainable than products made from fossil-based plastics in certain scenarios, such as resource conservation and carbon footprint. However, whether the biobased plastics can meet the material requirements and the high standards of medical devices, and to what extent the additives necessary for medical applications compensate for the environmental advantage is an important issue, as the environmental categories of eutrophication potential and ozone depletion can be negatively affected by the use of bio-based plastics. In this study, the requirements for the disposable product infusion bag, its life cycle, and its effects as well as the implications for the material properties are analyzed. To this end, a process analysis is carried out and the effects on the processing of these plastics are evaluated.

Keywords: Bioplastics, Medical Devices, Disposals

Paper Session 16: Safe and Sustainable by Design I
Thursday, 11th September - 14:00 - 16:00

Aula Magna

Towards Addressing Co-Creation Gaps: Automating Safe-and-Sustainable-by-Design Workflows with Electronic Lab Notebooks
(ID 74)

Nina Jeliazkova (Ideaconsult Ltd)*; Nikolay Kochev (Ideaconsult Ltd); Luchesar Iliev (Ideaconsult Ltd); Vedrin Jeliazkov (Ideaconsult Ltd); Giampaolo Campana (University of Bologna - School of Engineering and Architecture)

Abstract. The Safe-and-Sustainable-by-Design concept integrates Safety Assessment and Life Cycle Assessment tools, to create a new systematic approach addressing challenges in chemical safety, environmental impacts, and material circularity. However, fragmented data sources, complex assessments, and a lack of efficient collaborative tools hinder its effective implementation. This work outlines a structured, co-creative approach to the Safe-and-Sustainable-by-Design process, leveraging automated workflows to overcome these challenges. A central component is an Electronic Lab Notebook configured to represent essential Safe-and-Sustainable-by-Design resources - chemicals, materials, (manufacturing) processes, and products/applications - while serving as a structured repository for laboratory experiments, hazard assessments, production safety, and environmental sustainability evaluations. These elements are integrated into a Safe-and-Sustainable-by-Design innovation and (re)design stage-gate workflow. With programmatic Application Programming Interface access, the Electronic Lab Notebook supports automated workflows, including material property prediction, structured and unstructured data retrieval from chemical and material databases, and integration with external assessment tools. Team members can add materials via a web interface, associate them with Safe-and-Sustainable-by-Design stages, and trigger automated assessments or data gap-filling. This modular approach allows a seamless mix of manual and automated assessments while ensuring structured documentation, organisation, and traceability. Unlike ad-hoc file-sharing, we expect Electronic Lab Notebook to foster real-time collaboration, helping decision-making through well-documented iterative Safe-and-Sustainable-by-Design workflows.

Keywords: Safe-and-Sustainable-by-Design, Electronic Lab Notebook, Data Management.

Strengthening value chains through SSbD: Insights from the BIO-SUSHY project
(ID 176)

Jesse De Pagter (Centre for Social Innovation (ZSI))*

Abstract. With Safe and Sustainable by Design (SSbD) becoming a cornerstone of EU research and innovation policy in the chemicals and materials domain, many projects face the challenge of translating this framework into practice. This contribution reflects on how SSbD principles are being integrated into the Horizon Europe BIO-SUSHY project, which develops PFAS-free, biobased and hybrid coatings for textiles, paper food packaging, and cosmetic glass. Beyond material safety and performance, the project explicitly addresses the resilience and sustainability of future value chains. Particular attention will be paid to how regulatory shifts, market volatility, and societal debates around PFAS create a highly dynamic context, generating both challenges and valuable opportunities for safe and sustainable innovation. By combining tools such as social acceptance studies and stakeholder engagement, BIO-SUSHY works to anticipate potential barriers and align innovation pathways with broader societal and environmental goals. This contribution shares early insights into the added value, but also the complexity, of embedding SSbD thinking into value chain development from the start. It highlights the need for interdisciplinary approaches, continuous monitoring of external developments, and strategies to build public trust and adaptability into emerging safe and sustainable solutions.

Keywords: Anticipatory governance, Precautionary principle, Risk management, Safe and Sustainable by Design

Micro-engineered capsules: a powerful tool in green chemistry
(ID 111)

Anna Costa (CNR-ISSMC)*; Simona Ortelli (CNR-ISSMC); Franco Belosi (CNR-ISAC); Alessia Nicosia (CNR-ISAC); Socorro Vázquez Campos (LEITAT); Camilla Delpivo (LEITAT); Ilaria Zanoni (CNR-ISSMC); Maurizio Vespignani (CNR-ISSMC); Sara Amadori (CNR-ISSMC); Chiara Artusi (CNR-ISSMC); Magda Blosi (CNR-ISSMC)

Abstract. To meet the requirements of a responsible and sustainable use of nanotechnology, and to expand the design possibilities for advanced multicomponent materials, we employed two spray-based methods (spray drying and spray freeze drying) with the aim of producing dry powders that preserve both the nanostructure and the compositional gradient of the original colloidal formulations. Two case studies, developed within separate European projects, are presented with a focus on the advantages these techniques offer in terms of reducing emission and release potential during manufacturing operations. In the first case, silver nanoparticles coated with hydroxyethyl cellulose were processed via spray drying and spray freeze drying to obtain dry powders intended for use in more complex cosmetic formulations. As part of the SSbD assessment framework, we focused on the results of an emission monitoring campaign carried out during lab-scale processing and showed that no significant emissions occur when operations are conducted under a chemical hood. In the second case, we investigated spray-dried (SD) and spray-freeze-dried (SFD) modified MWCNTs as reinforcing fillers for polypropylene plastics produced via laboratory-scale extrusion. We compared the dustiness levels of pristine and modified CNTs. The modified samples exhibited a significantly lower dust release, by approximately two orders of magnitude, highlighting their potential to reduce worker exposure during manufacturing processes. This approach not only enhances safety by containing and controlling nanoscale materials, but also promotes sustainability by preserving material efficiency and reducing environmental risks, a crucial step toward responsible nanotechnology development.

Keywords: Spray-drying, Spray-freeze-drying, SSbD, nanotechnology.

Advancements in sustainable aqueous Zn-ion batteries via exploring new cathode & anode optimisation strategies
(ID 116)

Mariam Maisuradze (University of Bologna)*; Min Li (Elettra Synchrotron Trieste); Shuang Liu (University of Bologna); Jasper Plaisier (Elettra Synchrotron Trieste); Marco Giorgetti (University of Bologna)

Abstract. Nowadays, with rapid increase of energy consumption, limited resources and long-lasting impact on the environment and human health, the advancements in energy storage field are essential. In this regard, batteries, especially the rechargeable systems, have an important role. Due to the drawbacks of lithium-ion systems, research is shifting towards sodium-ion and more sustainable aqueous systems. In this regard, aqueous zinc battery systems attract interest, especially in a grid application, due to the low cost of Zn, its nontoxicity, high theoretical gravimetric and volumetric capacity.

Needless to say, the development of the electrode materials for the new battery systems becomes necessary. The Prussian Blue and its analogues have drawn the interest towards them as potential cathode materials with an attractive structural and electrochemical properties, especially manganese hexacyanoferrate, with two redox active couples (Fe3+/Fe2+ and Mn3+/Mn2+), which is also safe, cost-effective and easy to synthesise. Using dopants or multi-metal approach also gave some promising results regarding the improved stability of the system. Concurrently, the research has been conducted on the anode side, handling the dendrite formation and shortcutting issues of standard Zn-metal anode.

Next-Generation Flame Retardant Additives: A Path Toward Sustainability and Safety
(ID 133)

Ana Serrano Lotina (CSIC)*; Elvira Villaro (Avanzare); Mónica Martinez (Avanzare); Julio Gomez (Avanzare); Miguel A. Bañares (CSIC); Magda Blosi (CNR); Simona Ortelli (CNR); Anna Costa (CNR); Andrea Brunelli (UNIVE); Elena Badetti (UNIVE); Alberto Martinez Sierra (RCSI); Marco Monopoly (RCSI); Jesús López de Ipiña (TECNALIA, Basque Research and Technology Alliance (BRTA)); Angela Saccardo (Swansea University); Shareen Doak (Swansea University); Rob Vandebriel (RIVM); Fleming Casee (RIVM); Willie Peijnenburg (RIVM); Hyunjoo Hong (EMPA); Bernd Novack (EMPA); Sarah Devecchi (Green Decision); Arianna Livieri (Green Decision); Lisa Pizzol (Green Decision); Danail Hristozov (Green Decision)

Abstract. Electric vehicles (EVs) have more than 100 years of history, but the recent acceleration within the global automotive industry toward EV technology has garnered significant attention. This shift aims to achieve sustainable and zero-emission transportation. In this context, one area of particular interest is the development of car battery cases made with composites to reduce the weight of existing batteries, which requires the use of flame-retardant additives for improving their functionality. Avanzare have developed an advanced material (AdMa) based on graphene oxide functionalized with chitosan. During the material and the process design safety and sustainability concerns have been evaluated, following the Safe-and-Sustainable-by-Design framework proposed by the European Commission.
In this context, the physicochemical identity, toxicity aspects, occupational exposure risks and life-cycle release to the enviroment of the AdMa was evaluated.
Finally, a SSbD Tier 2 action has been addressed to replace chitosan with another environmentally friendly flame retardant additive (casein) that is easily recoverable by waste or by-products of the cheese and milk industry. This was motivated because although chitosan is a relatively non-toxic, biocompatible material, care must be taken to ensure that it is pure, as protein, metal or other contaminants could potentially cause many deleterious effects.
Physico-chemical properties were also measured and compared with the former AdMa.
Functionality of both materials was evaluated in the final product (polyamide 6 doped with the functionalized graphene oxide). This includes flammability and mechanical strength tests.

Keywords: Augmented Reality, End of Life, User Centered Design

Calcium Ferrites: Innovative and Multifunctional Solutions for Wastewater Treatment
(ID 4)

Maurizio Vespignani (ISSMC-CNR)*; Matheus Araùjo (Universidade Federal de Vicosa); Juliana Cristina Tristao (Universidade Federal de Vicosa); Mauro Mazzocchi (ISSMC-CNR); Magda Blosi (ISSMC-CNR); Ilaria Zanoni (ISSMC-CNR); Simona Ortelli (ISSMC-CNR); Chiara Artusi (ISSMC-CNR); Sara Amadori (ISSMC-CNR); Milad Takhsha (IMEM-CNR); Anna Luisa Costa (ISSMC-CNR)

Abstract: Addressing water pollution issues requires innovative solutions and global cooperation for sustainable water resources. In this study, the design of calcium ferrites nanoparticles was optimized by investigating different Ca:Fe molar ratios, calcination temperatures, and synthesis methods: thermal decomposition (TD) and sol-gel combustion (SG). We evaluated the magnetic behavior, the photocatalytic degradation of cationic/anionic dyes (methylene blue, MB; methyl orange, MO) and the adsorption of phosphates (PO_4^{3-}). We found that only SG samples exhibited superparamagnetic behaviour, with high value of saturation magnetization (5 to 40 $Am^2\ kgFe^{-1}$). TD samples showed superior photocatalytic activities, up to 4.5 mg g^{-1} for MB and 2.0 mg g^{-1} for MO. The phosphate adsorption capacity of both TD and SG CaFe_1:1 samples was very promising, with values exceeding 100 mg g^{-1} for TD samples and ranging between 50– 100 mg g^{-1} for SG samples. We systematically investigated the structural and colloidal properties to identify which design parameters most significantly affected the functional ones. Photocatalytic activity and phosphate adsorption capacity were found to be strongly dependent on the crystal phase of the samples. The samples exhibiting the highest activity were those containing brownmillerite (Ca2Fe2O5), followed by those containing hematite. The orthorhombic off-spinel phase (O-CaFe2O4) did not exhibit significant activity unless brownmillerite or hematite crystalline were also present. Finally, only SG samples Ca:Fe 1:2_300- 750 in the presence of both cubic spinel phase (C-CaFe2O4) and brownmillerite showed relevant magnetic and photocatalytic activities, with SG sample Ca:Fe_1:2_500 exhibiting the highest photocatalytic efficiency. The other physicochemical properties had little influence on the reactivity of the investigated ferrite phases, including specific surface area, which was significantly higher for the SG samples compared to the TD samples.

Keywords: Calcium ferrites, water remediation, photocatalysis, dyes degradation, phosphate adsorption, magnetism.

Paper Session 17: Production Planning and Control I
Thursday, 11th September - 14:00 - 16:00

Aula B

Opportunity Costs in Production Full Cost Accounting: A Systematic Literature Review (ID 65)

Dennis Hertell (Laboratory for Machine Tools and Production Engineering (WZL) at RWTH Aachen University)*; Günther Schuh (Laboratory for Machine Tools and Production Engineering (WZL) at RWTH Aachen University and Fraunhofer Institute for Production Technology IPT at RWTH Aachen University); Seth Schmitz (Laboratory for Machine Tools and Production Engineering (WZL) at RWTH Aachen University); Calvin Kuhn (Laboratory for Machine Tools and Production Engineering (WZL) at RWTH Aachen University)

Abstract. In recent years, shorter product lifecycles, individualization, and mass customization have led to an increase in product variety. The increase in product variety leads to inefficiencies in production, such as frequent changeovers or higher stock levels. Full cost accounting in production is essential for identifying inefficiencies and optimizing production by allocating all direct and indirect costs to products. However, established approaches for production full cost accounting do not properly account for inefficiencies due to product variety. As product variety increases, inefficiencies rise exponentially, contributing to opportunity costs. Opportunity costs represent revenue losses resulting from the nonproductive utilization of production resources. To accurately assess production costs and optimize production resource utilization, opportunity costs due to product variety must be included in production full cost accounting. Neglecting opportunity costs distorts cost assessments, leads to uneconomic portfolio decisions, and reduces production efficiency. For this purpose, this paper conducts a systematic literature review to identify approaches for opportunity costs in production. The findings categorize relevant cost types and outline how opportunity costs are addressed in production full cost accounting. Based on the categorization, novel cost types are proposed for the quantification of opportunity costs in production full cost accounting, and research gaps are identified.

Keywords: Opportunity Costs, Full Cost Accounting, Production Variance.

An Analytical Framework for Literature Review on Application of Manufacturing Efficiency Methods for Environmental Impact Reduction in the Fashion Industry (ID 110)

Côme Citroën (Institut Français de la Mode)*; Andrée-Anne Lemieux (Institut Français de la Mode); Steve Evans (University of Cambridge)

Abstract. Over the past decades, ever increasing production volumes have made the fashion industry a major contributor to anthropogenic climate change and numerous other types of pollution. As a result, the garment industry has been urged by scientists, lawmakers and consumers to reduce its environmental impact. With the majority of impacts being caused at the production stage, ambitious and rapid environmental gains can be aimed for through the improvement of manufacturing practices. While a large number of manufacturing methods - such as Lean Manufacturing, Six Sigma or Agile Method - have been thoroughly applied and studied in sectors such as automotive and electronics, academic literature on their use in the fashion industry remains relatively lacking, let alone for environmental impact. As a result, a cross-analysis framework was developed to qualify industrial performance methods in terms of potential environmental impact improvement and their applicability to the fashion industry. Subsequently, the literature review was conducted and showed major gaps in the literature, highlighting opportunities for future intervention research on the implementation of sustainable manufacturing practices in fashion supply chains, including aspects such as partnerships and governance practices, stakeholder engagement, and best operational practices and metrics.

Intralogistic Value Creation – Potential of mobile assembly processes
(ID 40)

Lukas Christ (Chair of Production Systems - Ruhr-University Bochum)*; Lennart Lamers (RIF Institute for Research and Transfer e. V.); Kai Gündisch (Chair of Production Systems - Ruhr-University Bochum); Bernd Kuhlenkötter (Chair of Production Systems - Ruhr-University Bochum)

Abstract. Current challenges in the industry, like the demand for sustainable production and the shortage of adequately skilled labor, necessitate more resourceconserving and therefore more efficient and sustainable processes and innovations. One promising approach to enhance production efficiency is intralogistic value creation, which involves parallelizing traditionally stationary value-creating production processes and currently non-value-creating intralogistic transport activities. By leveraging mobile robotic systems, such as mobile robot manipulators, it becomes possible to combine transport tasks with value-creating production operations. However, implementing such processes introduces technical challenges, including oscillation behavior, constrained workspaces, limited payload capacities, and compatibility with applicable joining processes. For this reason, this paper presents an approach for evaluating the potential of assembly processes for mobile applications with mobile robots to implement intralogistic value creation. This potential analysis uses a multi-stage evaluation based on a standardized process description of the applications under the assessment, considering technological and economic aspects. This approach aims to establish a standardized evaluation method that enables a quantifiable and, thus, objectively comparable assessment. This allows only processes with high success potential to be considered for more detailed and resource-intensive feasibility studies, whether in simulations or practical experiments.

Keywords: Production Efficiency, Resource Utilization, Mobile Assembly, Intralogistic Value Creation, Mobile Robot Manipulator.

Energy and Emission Impact Assessment of Path Planning in Four-Way Shuttle-Based Storage Systems
(ID 127)

Marco Ricci (University of Bologna)*; Riccardo Accorsi (University of Bologna); Ilaria Battarra (University of Bologna); Giacomo Lupi (University of Bologna); Riccardo Manzini (University of Bologna); Gabriele Sirri (University of Bologna)

Abstract. Automated shuttle-based storage and retrieval systems are widely used in warehouses and distribution centers to improve efficiency, accuracy, and space utilization. A special class is represented by the four-way shuttle-based storage and retrieval system where handling robots can move in four directions (forward, backward and sideways) within the racking system. This study introduces a methodology to assess energy consumption and the emissions of multiple handling robots in a shuttle-based automated storage and retrieval system. The application of a path planning simulation model assigns the actual routing to shuttles and allows for the computation of the corresponding impacts. Moreover, the paper presents the application to a realistic industrial environment using a multi-scenario comparative and competitive analysis. This analysis identifies the most critical energy-efficiency leverages in the path planning of multiple handling robots.

Keywords: Environmental sustainability, throughput, deep-lane storage system, logistics, warehousing systems, energy-based, life cycle assessment – LCA, CO2eq

Enhancing Production Planning and Control by Integrating the Circular Strategy `Repair´ (ID 43)

Jonah Schulz (Leuphana University Lüneburg)*; Jost Runte (Leuphana University Lüneburg); Alexander Rokoss (Leuphana University Lüneburg); Roman Krämer (Leuphana University Lüneburg); Matthias Schmidt (Leibniz University Hannover)

Abstract. Production planning and control (PPC) is a central task for manufacturing companies to align the logistical performance of production to customer requirements. Alongside well-established customer requirements such as delivery time and quality, sustainability-related criteria are gaining importance for maintaining competitiveness. In response, many manufacturing companies are increasingly adopting circular economy principles, also known as circular strategies. A promising approach to integrate circular strategies into production processes is the `repair´ strategy, in which end-of-life products are restored to full functionality to extend their lifespan. However, due to fluctuations in the availability and quality of end-of-life products, the resulting interactions with existing processes lead to new challenges for PPC. Despite repair´s increasing role in circular production systems, its specific impact on PPC and related interdependencies remains unexplored. For this reason, the present paper deals with the systematic identification and deductive derivation of resulting interdependencies within PPC that emerge from integrating the `repair´ strategy and embeds these findings within an existing PPC framework model. Ultimately, this paper contributes to a deeper understanding of how repair as a circular strategy affects PPC processes and provides a foundation for future framework development in this research area.

Keywords: Circular Economy, Production Planning and Control, Circular Strategies, Repair

Towards Simulation-Driven Framework for Optimising Rail Depot Operations and Maintenance Scheduling (ID 160)

Cansu Kandemir (AMRC)*; Marco Franchino (AMRC); Christopher Haynes (AMRC); Hassna Louadah (University of Huddersfield)

Abstract. Efficient and sustainable Train Fleet Maintenance (TFM) is crucial for maximising the environmental benefits of rail transport. This paper presents an integrated framework that combines short-term maintenance scheduling optimisation with Discrete Event Simulation (DES) to enhance the adaptability, reliability, and sustainability of depot operations. The scheduling tool, based on Mixed Integer Programming and a formal ontological model, generates cost-efficient maintenance plans while considering operational constraints. These plans are then validated through a detailed DES model developed in AnyLogic, which replicates real-world depot layouts, rules, and resource capacities. The simulation enables early detection of conflicts, supports proactive adjustments, and reduces unnecessary movements, energy/fuel use, and emissions. A realistic case study demonstrates how the integrated approach supports continuous improvement, ensuring operational feasibility and improved asset utilisation. The findings highlight the value of combining optimisation and simulation to support greener, more resilient maintenance planning. Future developments include a formal validation framework to further strengthen decision-making capabilities and support the transition towards low-carbon rail systems.

Keywords: Scheduling, Rolling Stock Maintenance, Rail Depot Management.es, water remediation, photocatalysis, dyes degradation, phosphate adsorption, magnetism.

Thursday, 11th September - 16:30 - 18:30			
Paper Session 18 **Education and Training**	**Paper Session 19** **Assessment of Sustainable Products**	**Paper Session 20** **Safe and Sustainable by Design II**	**Paper Session 21** **Product Planning and Control II**
Virtual Remotes Teaching Laboratories in the Progress of a Sustainable Education (ID 62)	A Comparative Study about Market Acceptance Fac tors of Sustainable Packaging Materials Between Finland and the United States (ID 27)	Hazard and Life Cycle Assessment of Safe and Sustainable Coatings (ID 101)	Direct and indirect electrification concepts based on induction heating for the substitution of gas-intensive production processes (ID 15)
Learning factory remanufacturing challenge: a hands-on training for circular economy (ID 8)	Comparative Environmental and Logistical Assessment of Reusable Packaging Systems in Fresh Produce Distribution (ID 184)	Hybrid Solid Surface Tension Modelling to Fill the Database Gap for Sustainable Textile Coatings (ID 132)	Deep Reinforcement Learning for Control Strategy Optimization of an Industrial Cooling Supply System in the Chemical and Pharmaceutical Industry (ID 109)
Regenerative Design Principles as Mindset Shifter for EESD Workshops: A Topic Analysis (ID 170)	Comparative Life Cycle Assessment of Ceramic and Plastic Caps for Swing-Top Bottles: A Case Study of a German Brewery (ID 80)	An Iterative Approach to Implement the Safe-and-Sustainable-by-Design Framework in Textile and Packaging Coatings (ID 125)	Design Methodology for Energy-Efficient Industrial Machines based on parametrised Life Cycle Assessment (ID 97)
Empowering SMEs for Circularity: A Competency-Based Learning Approach (ID 26)	A Framework for Assessing the Sustainability of Agri food Systems: A Case Study of the Cinnamon Industry (ID 120)	SSbD Industrial Case Study: Sustainable Alternatives to Anti-Stick Coatings for Aluminum Molds in Bakery Application (ID 114)	Enhancing Paint Utilization in Railcar Manufacturing Using a Sustainable Deep Deterministic Policy Gradient Approach (ID 76)

Paper Session 18: Education and Training
Thursday, 11th September - 16:30 - 18:00

Aula C

Virtual Remotes Teaching Laboratories in the Progress of a Sustainable Education (ID 62)

José Alejandro González Medina (University of Las Palmas de Gran Canaria)*; Paula González Suárez (University of Las Palmas de Gran Canaria); Pedro Manuel Hernández Castellano (University of Las Palmas de Gran Canaria)

Abstract. Education plays a crucial role in sustainable development. The correct transmission of knowledge, creativity, and critical thinking to the next generations is essential to guarantee the health of modern society. However, data shows that absenteeism and failure among students remain significant issues. Particularly in engineering, a fundamental field for the progress of communities and the quality of life, there seems to be a lack of enthusiasm among new generations. Additionally, in this age of Industry 4.0, the rapid pace of technological advancement means that educational content often fails to align with the realities of the industry. For these reasons, the University of Las Palmas de Gran Canaria (ULPGC) has initiated a project aimed at incorporating virtual remote teaching laboratories (VRTL) to enhance engineering education. The goal is to facilitate practical training for students through digital twins that emulate the educational use of university equipment. This approach is intended to foster easier and more effective competency development, keeping students motivated while reducing material resource consumption. This work presents an analysis of the prototype and testing of a VRTL focused on a laser cutting machine, demonstrating the effectiveness and potential future development of this concept.

Keywords: Remote laboratories, engineering education, digital twins, Industry 4.0.

Learning factory remanufacturing challenge: a hands-on training for circular economy (ID 8)

Kai Rüdele (Graz University of Technology)*; Matthias Wolf (Graz University of Technology); Christian Ramsauer (Graz University of Technology)

Abstract. Learning factories (LFs) have become an integral element of engineering education, especially when it comes to making new and on-trend subjects tangible. This also includes the abstract matters of sustainability and circular economy (CE), which are influenced by the design of products and production, and therefore closely linked to engineering expertise. This article presents how a new learning module was used to implement CE principles within a specific LF to foster sustainable practices and education. As a starting point, engineering students were familiarized with fundamental knowledge of CE. Following this, they were tasked with developing their own concepts for a disassembly line that reprocesses returned product components in the most ecological and economic way. These student-generated designs were discussed, evaluated, and have proven to be basically operable and effective. By integrating theoretical inputs with direct applications, this initiative not only enhances students' understanding of CE, but also enables them to implement it in actual operational practice. Additionally, our research is a first step towards the institutionalization of CE practices within a realistic learning environment. The findings and recommendations contribute to the broader discourse on education for sustainability and the role of LFs in promoting environmentally conscious industrial processes.

Keywords: circular economy, learning factory, engineering education, R-strategies

Regenerative Design Principles as Mindset Shifter for EESD Workshops: A Topic Analysis
(ID 170)

Zhe Sun (Tongji University); Lisha Ren (Tongji University)*; Harald Gruendl (Institute of Design Research Vienna)

Mindset transition becomes an emerging issue for engineering education in sustainable development (EESD). In this paper, we present an intensive workshop involving regenerative principles as stimuli, to explore how regen-erative principles resonate and influence students' thinking. Various formats of data in the center of students' discourses are collected, analyzed and charted in the four snapshots of the two-day workshop. Based on topic simi-larity results, we attempt to quantitatively visualize the dynamic change of concept development in each stage. The findings reveal that Reciprocity among the seven principles shows great potential in resonating and activat-ing students' ideation process. And the nature-inspired strategy spontaneous-ly formed and adapted in the process largely expands the ideation divergence. Regenerative-oriented pedagogical experiments also reflect the interconnect-edness between mindset transition and future literacy, vision towards regen-erative futures guides students' design decisions.

Empowering SMEs for Circularity: A Competency-Based Learning Approach
(ID 26)

Benjamin Gellert (Fraunhofer IPK)*; Katrin Singer-Coudoux (Fraunhofer IPK); Ayla Antonia Eser (Fraunhofer IPK); Ronald Orth (Fraunhofer IPK)

Abstract. To achieve true sustainability, manufacturing companies must transition from a linear to a circular economy. This requires well-trained professionals, particularly in product design, where crucial decisions about a product's circularity are made. New or adapted circular competencies are therefore essential. Small and medium-sized enterprises (SMEs), however, often lack the resources to systematically develop and implement training strategies for such socio-ecological transformations. The research project SustainAble addresses this challenge by proposing a competency catalog that enables SMEs to identify the circular economy competencies relevant to their workforce, with an additional focus on circular product design. This paper outlines the development of the catalog. The methodology combines a systematic literature review of circular economy competency models with AI-assisted profiling using JobCraftAI, a generative AI tool developed by the project IT partner. The identified competencies were systematically synthesized, categorized, validated in expert workshops and compiled in the SustainAble Competency Catalog. The result comprises 81 general circular economy competencies and 53 product design-specific competencies grouped into 20 competency categories. This research shows a practical framework for competency development and supports future applications such as adaptive learning and targeted training strategies.

Keywords: circular economy, competency, competency development, product design, SMEs, organizational learning.

Paper Session 19: Assessment of Sustainable Products
Thursday, 11th September - 16:30 - 18:00

Aula A

A Comparative Study about Market Acceptance Fac tors of Sustainable Packaging Materials Between Finland and the United States
(ID 27)

Piia Kanto (Tampere University of Applied Sciencies)*; Mika L. Nieminen (Tampere University of Applied Sciencies); Virpi Rämö (Tampere University of Applied Sciencies); Katri Salminen (Tampere University of Applied Sciencies)

Abstract. This study clarifies the decision-making factors that might hinder or enable replacing of packaging materials (fossil-based, non-biodegradable) with sustainable (i.e., recyclable, biodegradable, or bio-based) alternatives. A survey was conducted in Finland and the United States for various industry segments and company sizes using open-ended and multiple-choice questions. The results give an indication on companies' sustainable packaging-related plans. There were differences between the countries in the companies' environmental strategies, factors seen important by companies and how sustainable materials (i.e., recyclable, biodegradable, and bio-based) are perceived. There were clear differences between countries regarding the current use of environmental strategies in companies (e.g., in Finland, 36% of the companies had circular economy strategy vs. only 3% in the US). This was directly related to the future plans of using more sustainable packaging options and the ability of Finnish respondents to identify different factors affecting the choice of packaging materials.

Keywords: Circular economy, Industry strategies, Sustainable packaging

Comparative Environmental and Logistical Assessment of Reusable Packaging Systems in Fresh Produce Distribution
(ID 184)

Beatrice Lupi (Università di Bologna); Riccard Accorsi (Università di Bologna); Ilaria Battarra (Università di Bologna); Beatrice Guidani (Università di Bologna); Emilio Ferrari (Università di Bologna); Riccardo Manzini (Università di Bologna); Marco Ricci (Università di Bologna)*; Michele Ronzoni (Università di Bologna)

Abstract. This study investigates the environmental and logistical implications of adopting Reusable Plastic Containers (RPCs) in the distribution of fresh fruits and vegetables. A combined approach based on Life Cycle Assessment (LCA) and digital twin modeling was applied to simulate different crate configurations and assess their performance. The analysis relies on primary data collected through on-field test campaigns, involving multiple product categories and crate formats with varying capacities. By comparing different operating scenarios, the study quantifies both environmental benefits and logistical savings, particularly in terms of unit load and vehicle utilization. The analysis includes a case study involving several major Italian retailers and a pooling service provider. Results obtained from the case study show measurable improvements in both areas, highlighting the potential of crate design choices to reduce environmental impacts while increasing handling efficiency. The methodology proves effective in supporting evidence-based decisions for more sustainable and efficient fresh food supply chains.

Keywords: Fresh food distribution, LCA, reusable plastic containers – RPC, Environmental Impact Assessment, Sustainable Logistics.

Comparative Life Cycle Assessment of Ceramic and Plastic Caps for Swing-Top Bottles: A Case Study of a German Brewery
(ID 80)

Charlotte Sturm (Bochum University of Applied Sciences); Erik Alexander Recklies (Bochum University of Applied Sciences)*; Lisa Trautmann (Bochum University of Applied Sciences); Semih Severengiz (Bochum University of Applied Sciences)

Abstract. Packaging materials have a significant impact on the environmental footprint of products. This also applies to beverage bottles. The present study compares the environmental impacts of different packaging scenarios for beer bottles considering ceramic and plastic swing-top closures, different label materials, and further parameters such as circulation rates and transport distances. The comprehensive life cycle assessment is based on data from a German brewery and provides results in the categories of global warming potential (GWP100), damage to human health, ecosystems, and resource availability. The results suggest that the choice of material has a differentiated impact on environmental effects: Assuming equal life spans, the different swing-top closures show a comparable GWP100 regarding the production phase. However, the use of plastic caps leads to a reduction of total life-cycle emissions of the whole packaging system due to the lower weight. This applies particularly to scenarios with more bottle circulations. Recycled paper for labels shows a 14% reduced GWP100 in the production phase compared to coated paper. In general, the study provides substantial contributions to the packaging and brewing industries by addressing the research gap in life cycle assessments of swing-top bottles and by offering practical implications as well as future research perspectives.

Keywords: Life cycle assessment, Packaging industry, Beverage, Ceramic, Plastic.

A Framework for Assessing the Sustainability of Agri food Systems: A Case Study of the Cinnamon Industry
(ID 120)

Hasith Gunasekara (University of Vocational Technology)*; JR Gamage (University of Moratuwa); Shantha Amarasinghe (University of Moratuwa)

Abstract. Addressing the growing population and its increasing demands on the ecosystem is a major challenge that society is facing. In particular, ensuring a stable and sufficient food supply is a vital goal for food production systems. Improving food production and consumption systems is at the heart of every discourse on sustainable development from both environmental and socioeconomic perspectives. Sustainable production and consumption requires a systems approach underpinned by design for sustainability and life cycle thinking as well as an integration of economic, environmental and social aspects. Accordingly, the aim of the study was set as to develop a framework to assess the sustainability of agri-food systems. A list of indicators to assess the sustainability of a production and consumption system was identified through a comprehensive literature review. Then the case study on cinnamon products was evaluated against the identified production-consumption indicators. The results were graphically presented as a decision-making tool for the cinnamon producers and the relevant researchers. Further, the framework applied in this study can be utilized for future research on agri-food design.

Keywords: Design for Sustainability, Sustainability indicators, agri-food design.

Paper Session 20: Safe and Sustainable by Design II
Thursday, 11th September - 16:30 - 18:00

Aula Magna

Hazard and Life Cycle Assessment of Safe and Sustainable Coatings
(ID 101)

Marcella Paula (HOLOSS - Holistic and ontological solutions for sustainability)*; António Nogueira (HOLOSS - Holistic and ontological solutions for sustainability); José Ferraz-Caetano (HOLOSS - Holistic and ontological solutions for sustainability); Eleonora Longhin (NILU, Department for Environmental chemistry and Health Effects, Health Effects Laboratory); Sivakumar Murugadoss (NILU, Department for Environmental chemistry and Health Effects, Health Effects Laboratory); Elise Rundén-Pran (NILU, Department for Environmental chemistry and Health Effects, Health Effects Laboratory); Maria Dusinka (NILU, Department for Environmental chemistry and Health Effects, Health Effects Laboratory); Naouale El Yamani (NILU, Department for Environmental chemistry and Health Effects, Health Effects Laboratory); Anja Verbič (Department of Catalysis and Chemical Reaction Engineering, National Institute of Chemistry, Ljubljana); Blaž Stres (Department of Catalysis and Chemical Reaction Engineering, National Institute of Chemistry, Ljubljana); Uroš Novak (Department of Catalysis and Chemical Reaction Engineering, National Institute of Chemistry, Ljubljana); Blaž Likozar (Department of Catalysis and Chemical Reaction Engineering, National Institute of Chemistry, Ljubljana); Germán Ferreira (HOLOSS - Holistic and ontological solutions for sustainability)

Abstract. The PROPLANET project develops innovative bio-based coatings for textiles, food packaging machinery, and glass, implementing a Safe and Sustainable by design (SSbD) approach in order to replace per- and polyfluoroalkyl substances (PFAS) compounds. A hazard assessment approach is carried out integrating a detailed toxicological in vitro assessment. Key toxicological endpoints, including cytotoxicity, genotoxicity, and pro-inflammatory response are analysed in the chemicals formulations that replace PFAS-based coatings to ensure safety for human health. Additionally, a Life Cycle Assessment (LCA) is conducted following ISO 14040/44 standards using SIMAPRO software to evaluate the environmental impact of these formulations. The applied combination of hazard assessment and LCA criteria allows for the development and optimisation of coatings with low health and environmental risks. Furthermore, these assessments support PROPLANET's PFAS-free coatings in meeting regulatory requirements and market demands by promoting safe, efficient, and ecofriendly solutions for industrial applications. The integration of these methodologies strengthens the transition toward safe and sustainable materials and products in a circular economy framework.

Keywords: Safety, Sustainability, PFAS, LCA, coatings.

Hybrid Solid Surface Tension Modelling to Fill the Database Gap for Sustainable Textile Coatings (ID 132)

giampaolo campana (University of Bologna)*; Luca Anzolin (University of Bologna); Nina Jeliazkova (IDEA Consult); Diana Lau (Fraunhofer Institute for Silicate Research ISC); Ruth Garcia (Leitat Technological Center); tamara piock (Fraunhofer Institute for Silicate Research ISC); Paz Aragon (Leitat Technological Center); Miika Nikinmaa (VTT); Alina Giesler (LGI)

Abstract. Perfluoroalkyl and polyfluoroalkyl substances represent a broad class of synthetic organic chemicals of industrial origin. They have applications in several fields, such as textile and packaging impregnation and coatings, electroplating, and fire-fighting foams, because of their worthy performance. Due to the high strength of the covalent bond between carbon and fluorine, these compounds are frequently designated as “forever chemicals”. They exhibit remarkable environmental persistence, leading to uncontrolled accumulations, and are thus considered harmful. From an eco-friendly perspective, the compelling challenge is generating a textile and packaging coating possessing hydrophobic and oleophobic properties without the hazardous fluorinated additives. The present work introduces the development of a hybrid modelling methodology to evaluate solid surface tension for textiles using Neumann’s equation of state alongside finite element method algorithms and experimental contact angle data. The aim is to provide a predictive tool for assessing optimal non-polluting and non-harmful coating conditions. Indeed, the estimation of solid surface tension - a crucial property in wetting, adhesion, and adsorption processes, which currently lacks direct measurement methods - will be employed to address the selection of those safe and sustainable coating materials and additives that perform better. Perfluoroalkyl and polyfluoroalkyl substances will not be used, contributing to ecological and environmentally friendly solutions.

Keywords: Textiles, Coatings, Solid Surface Tension, Perfluoroalkyl substances, Polyfluoroalkyl substances.

An Iterative Approach to Implement the Safe-and-Sustainable-by-Design Framework in Textile and Packaging Coatings (ID 125)

Panagiotis Isigonis (Luxembourg Institute of Science and Technology)*; Federico Busio (Luxembourg Institute of Science and Technology); Elise Morel (TEMAS Solutions GMbH); Blanca Suarez-Merino (TEMAS Solutions GMbH); Imad Audi (LGI Sustainable Innovation); Mathilde Legay (LGI Sustainable Innovation); Miika Nikinmaa (VTT); Hille Rautkoski (VTT); Erno Karjalainen (VTT); Mika Vaha-Nissi (VTT); Diana Lau (Fraunhofer ISC); Tamara Piock (Fraunhofer ISC); Somchith Nique (Fraunhofer ISC); Ruth Garcia (LEITAT); Paz Aragón Chivite (LEITAT); Giampaolo Campana (University of Bologna); Nina Jeliazkova (IdeaConsult Ltd); Nikolay Kochev (IdeaConsult Ltd); Fujiao Cui (VTT)

Abstract. The Safe-and-Sustainable-by-Design (SSbD) systemic approach enables the integration of safety and sustainability assessment during the earliest stages of innovation, thus facilitating the research and introduction into the market of innovative materials and novel (manufacturing) processes. Due to their usage in multiple applications and for their persistence in the environment, per- and poly-fluoroalkyl (PFAS) substances have become an imminent matter of environmental concern on a global scale. Indeed, they can exhibit unique amphiphilic properties of significant interest in several industrial fields, fostering their use in applications. Besides, the remarkable strength of the carbon-fluorine bond characterises these compounds and determines their nondegradability. Due to their extensive use in industrial products and their persistence, PFAS substances caused a continuous release and accumulation in the environment. Eventually, recent investigations have discovered their hazardous and harmful effect on human and animal health. The paper proposes an iterative approach, performed within the ZeroF project (www.zerof.eu), based on the SSbD framework and used to identify chemical components and additives to substitute PFAS to produce innovative coatings for textile and packaging applications. The approach optimises the coating composition, manufacturing and deposition process. It considers environmental impacts of the coated products, estimated costs and the safety assessment.

Keywords: Textiles, Packaging, Coatings, Safe-and-Sustainable-by-Design, Per- and polyfluoroalkyl substances.

SSbD Industrial Case Study: Sustainable Alternatives to Anti-Stick Coatings for Aluminum Molds in Bakery Application
(ID 114)

Magda Blosi (CNR ISSMC)*; Ilaria Zanoni (CNR ISSMC); Andrea Brigliadori (CNR ISSMC); Simona Ortelli (CNR ISSMC); Anna Luisa Costa (CNR ISSMC); Mariajosé Lopez Tendero (Laurentia Technologies); Ana Serrano Lotina (c.CSIC Consejo Superior de Investigaciones Científicas, Madrid); Miguel Banares (CSIC Consejo Superior de Investigaciones Científicas, Madrid); Andrea Brunelli (Università Cà Foscari Venezia); Elena Badetti (Università Ca' Foscari Venezia); Willie Peijnenburg (RIVM Rijksinstituut voor Volksgezondheid en Milieu, Bilthoven, The Netherlands); Rob Vanderbriel (RIVM Rijksinstituut voor Volksgezondheid en Milieu, Bilthoven, The Netherlands); Carlos Fito (ITENE Centro Tecnológico. Embalaje, Transporte y Logística, Valencia); Angela Saccardo (Swansea University, Wales, UK); Shareen Doak (Swansea University, Wales, UK); Hyunjoo Hong (EMPA Swiss Federal Laboratories for Materials Science and Technology, St. Gallen); Bernd Nowack (EMPA Swiss Federal Laboratories for Materials Science and Technology, St. Gallen); Sarah Devecchi (GREENDECISION SRL, Mestre); Arianna Livieri (GREENDECISION SRL, Mestre); Lisa Pizzol (GREENDECISION SRL, Mestre); Danail Hristozov (EMERGE Ltd, Sofia)

Abstract. We present one of the four industrial case studies developed by the EU project SUNSHINE, focusing on anti-stick coatings for aluminum molds used in bakery applications. Traditionally, PTFE coatings have been preferred for their anti-stick properties. However, EU Reach regulations are imposing stricter limits on PTFE because of concerns about the release of harmful PFAS compounds. To address this, Laurentia Technologies has developed a sol-gel coating with a SiC@TiO2 core-shell nanostructure as an alternative to PTFE, aimed at creating a Safe and Sustainable by Design (SSbD) solution. The SiC-based nanoparticles enhance thermal conductivity, reducing cooking times and temperatures while improving durability and anti-stick properties. However, concerns about the use of TiO2 nanoparticles in food led to the development of a second alternative, SiC@SiO2, which offers similar benefits without the risks associated with TiO2. Both SiC@TiO2 and SiC@SiO2 coatings were rigorously tested for safety, functionality, and sustainability, covering their entire lifecycle from synthesis to end-of-life. Results showed that both alternatives perform well technically and have lower eco-toxicological impacts compared to PTFE. SiC@SiO2 demonstrated even lower environmental and economic impacts. Overall, these coatings offer promising, safer, and more sustainable replacements for PTFE.

Keywords: multicomponent nanomaterials, antistick coating, Safe and Sustainable by Design (SSbD), SiC@TiO2, SiC@SiO2

Paper Session 21: Production Planning and Control II
Thursday, 11th September - 16:30 - 18:00

Aula B

Direct and indirect electrification concepts based on induction heating for the substitution of gas-intensive production processes
(ID 15)

Anja Rautenstrauch (Technische Universität Chemnitz, Institute of Machine Tools and Production Processes IWP)*; Till Clausmeyer (Chemnitz University of Technology, Professorship Forming Technology); Alexander Fröhlich (Chemnitz University of Technology, Professorship Forming Technology); Martin Kroll (Chemnitz University of Technology, Professorship Forming Technology)

Abstract. The substitution of gas-intensive production processes with electrothermal technologies represents a crucial step toward sustainable manufacturing. One long-established method for converting electrical energy into thermal energy is induction heating. A key aspect of replacing gas-intensive heating processes with electric heat is the design of the heating system. This involves specific challenges related to the heating task, such as the design of induction coils, inverter technologies, and the targeted use of suitable materials. This paper presents various concepts for using direct and indirect electric heating processes to address the fundamental challenges in industrial manu-facturing processes and initiate climate-friendly and sustainable production. It showcases two different solutions along production process chains, in particular the use of induction technology for hot gas generation and for selective sheet metal heating. The development of these systems is based on years of experience, advanced computer-aided simulation methods, and the use of novel materials.

Keywords: gas-intensive production, electrothermal technology, heating system

Deep Reinforcement Learning for Control Strategy Optimization of an Industrial Cooling Supply System in the Chemical and Pharmaceutical Industry
(ID 109)

Tobias Lademann (PTW, TU Darmstadt)*; Arthur Stobert (PTW, TU Darmstadt); Heiko Ranzau (PTW, TU Darmstadt); Jonas Klingelhöfer (PTW, TU Darmstadt); Manuel Scharfe (PTW, TU Darmstadt); Matthias Weigold (PTW, TU Darmstadt)

Abstract. Control optimization of industrial energy supply systems is essential for the global energy transition and the reduction of energy costs for industry. Deep Reinforcement Learning (DRL) can optimize the control strategy of complex energy supply systems considering volatile external influences such as weather or electricity prices. This work implements and evaluates the DRL application for an industrial cooling supply system from the chemical and pharmaceutical industry. The simulation model of the system for training and performance evaluation is based on datasheets and historical data. Parameter identification is used to reduce the relative model error from 19 % to 10 % with respect to cumulative electric energy consumption over a five-month period. The DRL based operation is benchmarked against the conventional rule-based control strategy in the simulation model. The results show that the application of DRL is suitable for identifying effective and energy efficient operating strategies. However, not all operating cost factors can be reduced equally and the trade-off between different optimization targets is challenging. Based on the simulation model and implementation of this work, the performance of the DRL strategy should be improved in future research.

Keywords: Energy Efficiency, Machine Learning, Parameter Identification

Design Methodology for Energy-Efficient Industrial Machines based on parametrised Life Cycle Assessment
(ID 97)

ANASTASIIA TIMOFEEVA (University of Bologna)*; Giampaolo Campana (University of Bologna); Gregory Peters (Chalmers University of Technology); Maurizio Fiorini (University of Bologna)

Abstract. This paper presents a design methodology for energy-efficient industrial automated machines based on Life Cycle Assessment (LCA) as a key analytical tool. In particular, the environmental performance of an industrial washing machine designed for the pharmaceutical sector is evaluated throughout its LCA performed in a cradle-to-grave boundary using the ReCiPe 2016 midpoint calculation method. The findings revealed that the use phase contributes the most to environmental impact, mainly due to energy consumption. Critical components for improvement were identified, and optimisation scenarios were proposed to enhance energy efficiency. A Total Estimated Energy Consumption framework, including operational states, has been applied to achieve a more comprehensive energy demand. Determining energy parameters for different operating states allows for a more accurate environmental impact evaluation. Parametrisation in LCA enables modelling of different energy consumption scenarios based on various factors of the machine's washing cycle and usage mode. This method allows manufacturers to compare energy-saving designs, operational improvements and sustainable energy strategies without rebuilding the entire LCA model. This work supports the development of sustainable industrial machines, aligning with circular economy principles and eco-design strategy.

Keywords: Sustainable Manufacturing, Life Cycle Assessment, Industrial Washing Machines, Energy Efficiency, Eco-Design.

Enhancing Paint Utilization in Railcar Manufacturing Using a Sustainable Deep Deterministic Policy Gradient Approach
(ID 76)

Olugbenga Aderoba (Tshwane University of Technology)*; Tshifhiwa Nenzhelele (Tshwane University of Technology); Jan Adriaan Swanepoel (Tshwane University of Technology); Genevieve Bakam (Tshwane University of Technology)

Abstract. Efficient application of paints is crucial in railcar manufacturing to minimize waste and environmental impact while ensuring high-quality coatings. This study presents a sustainable approach to optimizing paint utilization in rail car manufacturing by applying the Deep Deterministic Policy Gradient (DDPG) algorithm. This was achieved by dynamically adjusting painting parameters such as the spray pattern, spray flow rate, nozzle angle, and distance to minimize the consumption of paints and solvents while maintaining uniform coverage and quality. Real-time sensor data from automated painting systems and historical painting records were utilized to learn optimal spraying policies that balance resource conservation with production requirements. Through simulations and experiments in a virtual manufacturing environment, the approach's effectiveness in improving paint application efficiency and reducing waste generation was demonstrated. The scalability and adaptability of the DDPG-based optimization framework are evaluated, highlighting its potential for practical implementation in real-world railcar manufacturing facilities. This research contributes to advancing sustainable practices in railcar manufacturing by providing a data-driven approach to optimize paint utilization, enhancing efficiency, and reducing the environmental footprint in painting processes.

Keywords: Railcar manufacturing, Deep Deterministic Policy Gradient, Paint utilization, Sustainable Manufacturing, Optimal spraying policies

Friday, 12th September - 10:30 - 12:30		
Paper Session 22 **Industry 5.0**	**Paper Session 23** **Corporate and Product Carbon Footprint Calculation**	**Paper Session 24** **Supply Chains**
Slow manufacturing: its conceptualization, application and research agenda (ID 88)	Decarbonizing Automotive Supply Chains: Methodology and Case Studies for LCA and CO2e Reduction (ID 177)	Artificial Intelligence and Blockchain Combined for Sustainability Reporting in Supply Chain Management – a Literature Review (ID 38)
Information Logistics as a Key Enabler for Biointelligent Value Creation Systems – Challenges and Requirements (ID 63)	Real-time monitoring of the production carbon footprint for SMEs (ID 183)	Optimizing reusable food packaging flows within a circular economy framework (ID 131)
Deriving Circular Economy Principles for Industrial Implementation - Operational Implications and Responsibilities within Company Boundaries (ID 3)	Integrated approach for calculating corporate and product carbon footprints in the textile industry (ID 56)	Simulation-based optimization for supply chains with multi-criteria target systems - A comparison of multiple algorithms (ID 13)
Implementation Concept for Sustainable Empathic Technical Systems (ID 32)	A Graph-Based Tool for Navigating Life Cycle Assessment Standards in Product Carbon Footprinting (ID 161)	Analysis of Local Mitigation Strategies for Material Procurement Risks for Sustainable and Resilient Manufacturing: A Simulation-based Approach for Linear and Non-linear Production Layouts (ID 135)
An Innovaative AI-Based Operational Framework for Industry 5.0 Towards Sustainable Manufacturing (ID 42)	An automated workflow for the PCF calculation of battery cells (ID 49)	Risk Mitigation and Sustainability in Oil Supply Networks: A Multi-Objective Optimization Approach (ID 79)
Industry 5.0-oriented training interventions: sustainability and pillars in the case of electronics manufacturing (ID 86)	Digital twin based framework to enhance the environmental sustainability of supply chains (ID 84)	Case study of Bochum and Chofu City in Installing E-Moped Sharing Service for Accessibility, Greenhouse Gas Emissions, and Cost (ID 189)

Paper Session 22: Industry 5.0
Fri, 12th September - 10:30 - 12:30

Aula A

Slow manufacturing: its conceptualization, application and research agenda
(ID 88)

Hideki Kobayashi (Osaka University)*; Haruto Katayama (Osaka University); Hidenori Murata (Osaka University); Barbara Cimatti (University of Bologna); Giampaolo Campana (University of Bologna)

Abstract. The manufacturing paradigm is transitioning from Industry 4.0 to Industry 5.0. While Industry 4.0 emphasised IoT technologies to enhance flexibility and efficiency, Industry 5.0 seeks to integrate these advancements with human-centric, sustainable, and resilient approaches. This paper introduces the concept of slow manufacturing, comprising three core elements rooted in craftsmanship, and explores its alignment with the goals of Industry 5.0. Practical and research-based examples from industrialised nations are presented, followed by an analysis of how these cases may be adapted for developing countries. A research agenda is then proposed and structured around the foundational elements of slow manufacturing. This approach suggests that adopting slowness in manufacturing can offer a viable pathway to realising the human-centred ideals of Industry 5.0.

Keywords: Slowness, Craftsmanship, Extra Value Creation, Industry 5.0.

Information Logistics as a Key Enabler for Biointelligent Value Creation Systems – Challenges and Requirements
(ID 63)

Arber Shoshi (University of Stuttgart)*; Thomas Bauernhansl (Fraunhofer Institute for Manufacturing Engineering and Automation IPA); Robert Miehe (Fraunhofer Institute for Manufacturing Engineering and Automation IPA)

Abstract. The concept of biointelligence has recently emerged as a convergence of biology, engineering and information technology. The use of biointelligent systems in decentralized, small-scale production units, designed for non-professionals, using local biological resources and involving different actors, constitute biointelligent value creation systems (BVC). The effective operation of BVCs requires an information system and the underlying system, namely information logistics, capable of providing the right information to the right actor at the right time and in the right quality. However, the inherent complexity of management, due among other things to biological components in the system and heterogeneous participants - including industrial and non-industrial actors - poses significant challenges to existing information systems. This paper addresses this gap by analyzing 19 expert interviews from industry and academia. It identifies key challenges such as a lack of semantic interoperability and unclear data ownership, as well as requirements for scalable, role-specific and adaptive information logistics systems. The findings provide actionable insights into how future information systems can be designed to support complex and dynamic BVC environments, including the importance of transparent governance structures and user-centered dashboards that address diverse stakeholder needs.

Keywords: Biointelligence, Information logistics, value creation systems, Sustainable production

Deriving Circular Economy Principles for Industrial Implementation - Operational Implications and Responsibilities within Company Boundaries
(ID 3)

Dominik Saubke (Helmut-Schmidt-University)

Abstract. In economics, new theoretical approaches have often emerged when our traditional paradigms surpassed their limits. Heterodox economic theories have increasingly gained attention, responding to shifting contextual factors and challenging infinite and unidirectional models resource use. Since the seminal works of STAHEL and REDAY (1976), the Circular Economy (CE) has become a central model for a sustainable economic transition in academic and political discussions, gaining significant traction over the last decade. However, much of the outcome of its discussions remains theoretical, with policymakers and institutions often overlooking the fact that successful implementation must occur at the company level. To address this gap, a social empirical research approach was conducted to identify and analyse 18 national and international strategy papers from governmental bodies, industry associations (e.g., ACATECH, VDI), and standardization organizations (e.g., DIN). Across over 1,000 pages of documentation, 14 Action Areas for implementing CE principles were condensed. The Action Areas are linked to 55 Operational Implications for industrial implementation, which were further assigned to 9 corporate responsibilities to ensure pragmatic and actionable recommendations.

Keywords: Manufacturing, Sustainability, Circular Economy, Management

Implementation Concept for Sustainable Empathic Technical Systems
(ID 32)

Eckart Uhlmann (Fraunhofer IPK); Julian Polte (Fraunhofer IPK); Philipp Lelidis (Fraunhofer IPK)*

Abstract. This paper presents an implementation concept for a sustainable Empathic Technical Systems developed in the Fraunhofer flagship project “EMOTION,” in which a novel approach to cooperative and decentralized production planning and control is being explored. By embedding empathic capabilities into traditional cognitive systems, ETS aim to address coordination challenges and optimize cooperation in increasingly complex industrial environments. The implementation of ETS enables the optimization of the entire production system in alignment with global goals such as sustainability, promoting environmentally friendly practices and responsible resource management. The concept of ETS ultimately contributes to the evolution of intelligent manufacturing systems by integrating affective and situational awareness, fostering enhanced collaboration between humans and machines. The concept demonstrates the implementation of the key requirements for successful ETS deployment, including perception through multimodal sensors, autonomous decision-making that aligns individual and collective goals, and continuous learning from interactions. The practical implementation of ETS is illustrated through the production of bipolar plates for fuel cells, highlighting the integration of advanced communication protocols and real-time data processing. By prioritizing human-centric approaches and sustainability, this research aims to pave the way for more resilient, adaptive, and efficient manufacturing systems that not only meet economic objectives but also promote social and environmental responsibility.

Keywords: Empathic Technical Systems, Distributed Manufacturing, Cooperation, Digital Twin.

An Innovaative AI-Based Operational Framework for Industry 5.0 Towards Sustainable Manufacturing (ID 42)

Gianluca Di Francesco (Opseed srl)*; Augusto Bianchini (University of Bologna); Francesco Manuzzi (Turtle srl); Alessandro Pompili (Opseed srl)

Abstract. Manufacturing transformation is driven by integration of performance improvement and sustainability. To this end, Artificial Intelligence (AI) acts as a key enabler, accelerating the transition from Industry 4.0 to 5.0. This study introduces an innovative AI-driven operational framework: Sustainable Operational Intelligence (SOI) developed by Opseed. The framework integrates human-machine collaboration, combining machine data, human activities (Work Process) and system elaborations (System Process) to build a corporate knowledge base. AI-driven processing enables natural language interaction with a manufacturing AI agent, able to extract insights to reduce losses and improve performance (Overall Equipment Effectiveness) and sustainability KPIs (CO2 equivalent emission (CO2e)). The framework was lab-tested on Collaborative Robot (Cobot) and Automatic Guided Vehicle (AGV) losses with two groups of not-expert operators, one using SOI and one without. Performance was evaluated based on Unplanned Downtime (UPDT) and daily CO2e per functional unit. The results show significant reduction in UPDT and CO2e per functional unit. Aligned with autonomous maintenance principles, SOI enhances operator autonomy with continuous and targeted loss support. Moreover, integrating sustainability indices into the framework enables automatic mapping and identification of improvement actions. Future work will extend to more failures and operators and be tested in automated packaging lines, addressing lab limitations.

Keywords: Industry 5.0, Operational Framework, Sustainable Manufacturing, ESG Compliance, Artificial Intelligence; Operational Intelligence

Industry 5.0-oriented training interventions: sustainability and pillars in the case of electronics manufacturing (ID 86)

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Abstract. Industry 5.0 represents a paradigm shift in manufacturing, prioritizing human-centric approaches, sustainability, and resilience alongside technological advancements. This study examines Industry 5.0 through a targeted training intervention in the electronics industry. The intervention aims at enhancing workforce upskilling while embedding specific practices within company operations. A comprehensive evaluation was conducted to assess both company-level impacts and individual skill development. The findings indicate the success in integrating Industry 5.0 into the training program. At the same time, the significance of sustainability as a core pillar of Industry 5.0 is highlighted, influencing production efficiency, environmental responsibility, and social well-being, through exploring the correlation between sustainability and the other two key Industry 5.0 pillars. The success of the intervention underscores the necessity of aligning technological progress with sustainable practices to achieve a balanced and future-ready industrial ecosystem. This study contributes valuable insights into the implementation of Industry 5.0 principles, emphasizing the crucial role of sustainability in shaping modern industrial evolution.

Keywords: Industry 5.0, Sustainability, Training.

Paper Session 23: Corporate and Product Carbon Footprint Caclulation
Fri, 12th September - 10:30 - 11:30

Aula C

Decarbonizing Automotive Supply Chains: Methodology and Case Studies for LCA and CO2e Reduction (ID 177)

Ulisse Millefanti (Ferrari spa)*

Abstract. This document presents a structured methodology for evaluating future material solutions and CO2e emissions in the automotive sector. By applying Life Cycle Assessment (LCA) aligned with ISO 14067 and the GHG Protocol, the study emphasizes the transition from primary to recycled materials particularly aluminum to achieve significant reductions in material-related emissions, with case studies showing over 70% CO2e reduction for a high-performance car body. A standardized data collection template was developed and implemented across the supply chain, enabling consistent, traceable, and comparable environmental data from suppliers. Over one year, 76% of suppliers provided complete data, demonstrating strong engagement and readiness to address sustainability challenges. The approach also explores innovative materials for battery applications, such as phase change materials, supporting the integration of circular economy principles. This methodology offers a replicable and scalable model for both industrial and academic applications, facilitating transparent environmental assessments and supporting the automotive industry's transition toward climate neutrality

Keywords: CO_2eq, sutainability, GHG protocol, methogology.

Real-time monitoring of the production carbon footprint for SMEs (ID 183)

Julian Sasse (FH Kiel)*; Prof. Dr. Henning Strauß (Fachhochschule Kiel)

Abstract The core of the research work is the development and implementation of a real-time production carbon footprint with a focus on applicability for small and medium-sized enterprises. Based on the implementation of a machine carbon footprint for a 5-axis universal machining center, consumption such as energy, compressed air, cooling lubricants and material consumption are dynamically recorded and visualized in real time with the help of a wide variety of sensors. The processing, storage and visualization of the measurement data are carried out using open-source low-code platforms. The data serves as a basis for both the product-related and production-specific CO_2 footprint. The aim is to provide an initial approach for SMEs that provides an entry point into sustainable production and at the same time provides increased transparency in production and helps with optimization and compliance with future regulatory requirements.

Keywords: CO_2 Footprint, Machine Data Acquisition, Production, Process Data, IoT, Open Source Software

Integrated approach for calculating corporate and product carbon footprints in the textile industry (ID 56)

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Abstract. The textile industry significantly contributes to global greenhouse gas emis-sions. Corporations are thus increasingly forced to calculate carbon foot-prints at both the corporate (Corporate Carbon Footprint, CCF) and product (Product Carbon Footprint, PCF) level. While both approaches are common-ly calculated separately, integrating them into a single analysis provides a more comprehensive understanding of emissions and facilitate targeted re-duction measures. This article proposes an approach to calculate the CCF in the textile industry, which integrates a methodology for PCF calculation via mathematical optimization for homogeneous product portfolios. The meth-odology exploits synergies between PCF and CCF calculations to ensure a consistent and efficient emissions analysis. The practical application of this model is demonstrated through a case study of the German textile SME 3FREUNDE, which is based on primary data from the supply chain and pro-duction processes. The results show that an integrated calculation reduces the burden of environmental assessment and provides a solid basis for effec-tive decarbonization strategies at the product and company level. This helps companies meet regulatory requirements and gain a sustainable competitive advantage.

A Graph-Based Tool for Navigating Life Cycle Assessment Standards in Product Carbon Footprinting (ID 161)

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Abstract. The proliferation of standards, protocols and norms in the field of Life Cycle Assessment (LCA) poses a major challenge for users seeking appropriate guidance for Product Carbon Footprint (PCF) studies. This paper presents a graph-based tool developed in Python using Pyvis to integrate and visualize this vast network of LCA standards. The interactive ESTAINIUM Standards Graph maps the relationships between the standards as nodes and edges and allows the user to filter by attributes such as scope, industry sector and geographical validity. Three important PCF standards are the central nodes of the graph: the GHG Protocol Product Standard, ISO 14067:2018 and EN 15804 for environmental product declarations. The results show that an interactive visualization significantly simplifies the search for the complex, interlinked standards and supports both decision-making and learning in the LCA community. This approach complements ongoing efforts to harmonize LCA/PCF methodologies, and the graphbased tool has been shown to be a fundamental reference for simplifying the identification of standards and improving understanding through a visual, interactive system.

Keywords: standards, norms, life cycle assessment, product carbon footprint

An automated workflow for the PCF calculation of battery cells
(ID 49)

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Abstract. The growing demand for sustainable battery production calls for advanced methodologies to efficiently assess environmental impacts. This is further driven by the European Battery Regulation, which imposes strict requirements on battery manufacturers regarding the Product Carbon Footprint (PCF), resulting in significant effort. One major challeng is the lack of complete, scalable and company specific Life Cycle Inventories (LCI). Moreover, assessment approaches often fail to align with how LCI-relevant data is structured and accessed within companies, leading to data integration challenges. This paper presents an automated workflow for the PCF calculation and assessment of battery cells. The workflow includes a parameterized tool for generating LCIs adapted to the circumstances at a German battery manufacturer. It facilitates the calculation of key parameters, such as material weights, scrap and energy density, which serve as the basis for LCI and for defining the functional unit. In addition, KNIME Analytics is utilized to facilitate data wrangling, allowing for the seamless transfer of LCI data into Life Cycle Assessment (LCA) software. Lastly, the results are presented through an intuitive Graphical User Interface (GUI), allowing stakeholders to easily interpret and use the results.

Keywords: Product Carbon Footprint, Automated Workflow, Battery cell.

Digital twin based framework to enhance the environmental sustainability of supply chains
(ID 84)

Madhurika Geeethani (University of Moratuwa)*; Asela Kulatunga (University of Exeter); Subodha Dharmapriya (University of Peradeniya)

Abstract. Digital twinning of any business process creates opportunities for integrating life cycle thinking to enhance the environmental sustainability of a supply chain with real-time monitoring and control through informed, timely decisions. This is made possible as a digital twin facilitates continuous data acquisition, visualization, and performs analytics including simulation modelling, machine learning, optimization and dynamic Life Cycle Assessment. This research presents the design and development of a decision support framework that applies life cycle thinking to guide the adaptation of digital twining for sustainable supply chain management. The proposed framework capitalizes on the ISO framework on digital twins (ISO 23247 Series) and expands towards upstream, core process and downstream activities of supply chains. It further incorporates simulation, data analytics and Life Cycle Impact Assessment aspects to facilitate decision support at strategic, tactical and operations levels, thereby contributing to the framework's uniqueness.

Keywords: Digital twin, Supply Chain, Environmental Sustainability

Paper Session 24: Supply Chains
Fri, 12th September - 10:30 - 12:30

Aula B

Artificial Intelligence and Blockchain Combined for Sustainability Reporting in Supply Chain Management – a Literature Review
(ID 38)

Michael Fiolka (TU Dortmund University)*; Luisa Strehl (Fraunhofer IML); Tobias Jornitz (Fraunhofer IML)

Abstract. Since the emergence of the blockchain and the uprising of chatGPT, the Distributed Ledger Technology (DLT) and Artificial Intelligence (AI) are well-discussed topics both in public and professional circles, but especially in the domain of Supply Chain Management (SCM). These subjects are tech-savvy, complicated to explain and even more complex to use. On top of that, there is a scientific discussion around synergies in combining both technologies. Together they can be useful in engaging current challenges in Supply Chain Management, where transparency-related data has to be generated, processed and formed into decisions and reports. To investigate the potentials of these technologies working together in a sustainability-reporting environment, we performed a systematic literature review. We also included literature focusing solely on the technological perspective. The objective is a comprehensive overview on how a combination of DLT and AI could help to solve current challenges arising from sustainability related regulations. Further, we discussed ideas around Internet of Things applications or Federated Learning approaches, that use data from different entities and can be used in sustainability reporting, exploring possibilities to enhance compliance and responsible business conduct in SCM.

Keywords: Sustainability, Blockchain, Artificial Intelligence.

Optimizing reusable food packaging flows within a circular economy framework
(ID 131)

Giorgia Bartolotti (University of Bologna)*; Beatrice Guidani (University of Bologna); Michele Ronzoni (University of Bologna); Riccardo Manzini (University of Bologna); Emilio Ferrari (University of Bologna); Riccardo Accorsi (University of Bologna)

Abstract. The agri-food industry is one of the most packaging-intensive sectors. Sustainability goals clearly indicate reusable packaging as a solution to reduce the environmental burdens of the food supply chain. While circular economy schemes are increasingly adopted for secondary and tertiary packaging, their large-scale implementation for primary packaging remains limited due to logistical and behavioral complexities. Closed-loop systems for reusable primary food packaging require coordinated direct and reverse flows, including filling, distribution, consumer return, sorting, and washing. Modeling these systems requires accounting for uncertainties such as return and breakage rates. This paper relies on a Mixed Integer Linear Optimization model to support the location-allocation of facilities and collection points in a reusable packaging network. The model integrates uncertainty in consumer behavior and packaging durability, quantifying their impact on cost, emissions, and system configuration. This paper tackles uncertainties in packaging return rates and breakage rates, capturing their impacts on overall supply chain performance and configuration. These insights support the design of more resilient reuse systems and inform policymakers in defining effective incentive schemes to scale up sustainable packaging practices in food supply chains.

Keywords: Reusable primary packaging, Circular economy, Consumer behavior, Risk analysis, Logistic optimization.

Simulation-based optimization for supply chains with multi-criteria target systems - A comparison of multiple algorithms
(ID 13)

Lucas Schreiber (Fraunhofer Institute for Material Flow and Logistics)*; Luca Bernstiel (Fraunhofer Institute for Material Flow and Logistics)

Abstract. In modern industrial applications, production and logistics systems are meticulously planned to minimize unexpected costs and ensure efficiency. Discrete-event simulation is a widely used tool for evaluating scenarios and configurations in a cost-effective digital environment. Beyond economic factors, eco-efficiency and sustainability have become crucial considerations due to the depletion of fossil resources and increasing regulatory pressure. Integrating ecological targets alongside cost and service-level objectives is essential for optimized corporate planning.

This paper explores the interaction between discrete-event simulation and optimization techniques to enhance system performance. Given the vast number of possible parameter combinations, advanced algorithms are necessary to find optimal solutions efficiently. Three metaheuristic approaches—Non-Dominated Sorting Genetic Algorithm II (NSGA-II), Particle Swarm Optimization (PSO), and Surrogate-Assisted Grey Wolf Optimization (SAGWO)—were implemented and compared. These algorithms were tested on a supply chain in the steel procuct industry, focusing on production allocation, warehousing strategies, and distribution optimization. A t-test confirmed their statistical significance in outperforming random solutions. The results demonstrate that integrating simulation with optimization algorithms provides strategic and iterative improvements in cost, service level, and energy consumption, contributing to more sustainable and efficient industrial operations.

Keywords: Simulation-based optimization, Supply Chains, Sustainability, Metaheuristics, Material Flow Simulation

Analysis of Local Mitigation Strategies for Material Procurement Risks for Sustainable and Resilient Manufacturing: A Simulation-based Approach for Linear and Non-linear Production Layouts
(ID 135)

Florian Sinn (TU Berlin)*; Benjamin Gorgas (TU Berlin); Frank Straube (TU Berlin)

Abstract. This paper presents a simulation-based analysis of local mitigation strategies for managing material procurement risks in manufacturing environments. Focusing on factory-level mitigation strategies, the study investigates how different types of procurement-related disruptions affect production efficiency and identifies and evaluates mitigation strategies - such as safety stock adjustments, procurement volume control and variable processing - that enhance resilience and sustainability. Two archetypal production layouts are considered. A linear assembly line and a non-linear fractal configuration. By systematically modeling risk scenarios across these layouts, the study evaluates the effectiveness of individual and combined strategies in maintaining stable and efficient production. The results highlight key interdependencies between risk type, factory layout and mitigation approach, offering actionable insights for production planners. These findings support the development of adaptive, locally resilient manufacturing systems capable of responding to supply volatility while contributing to broader sustainability objectives.

Keywords: Procurement Risk Management, Simulation-based Analysis, Resilient Manufacturing, Linear and Non-linear Production, Local Mitigation Strategies, Multifactorial Experiments.

Risk Mitigation and Sustainability in Oil Supply Networks: A Multi-Objective Optimization Approach
(ID 79)

Alperen Bal (American University of the Middle East)*; Hakan Tozan (American University of the Middle East); Oumayma Hamlaoui (American University of the Middle East); Mohammad Kareem Hajji (American University of the Middle East)

Abstract. Oil supply chains are a critical infrastructure for both nation's economies and global energy markets. However, these supply chains face disruptive risks from sudden refinery outages and pipeline capacity losses to geopolitical events that can interrupt oil flows. Simultaneously, stricter environmental regulations, particularly on sulfur emissions, demand cleaner fuel production and operations. This study develops a multi-objective optimization model to enhance the resilience of oil supply chains in the Gulf region while balancing economic and environmental objectives. The model minimizes total supply chain cost and sulfur emissions, and maximizes resilience, under three disruption scenarios: (1) refinery shutdowns, (2) pipeline capacity reductions, and (3) geopolitical supply constraints. The formulation incorporates sulfur emission regulations and broader environmental policies as constraints. Scenario analyses are conducted to evaluate trade-offs among cost efficiency, compliance with sulfur caps, and the ability to sustain supply during disruptions. The results are expected to provide decision-makers with a set of Pareto-optimal strategies that reinforce supply chain resilience against disruptions, ensure regulatory compliance, and manage costs effectively.

Keywords: Supply Chain Resilience · Risk Mitigation · Multi-objective Optimization · Oil Supply Networks · Sustainable Manufacturing.

Case study of Bochum and Chofu City in Installing E-Moped Sharing Service for Accessibility, Greenhouse Gas Emissions, and Cost
(ID 189)

Seigo Takahashi (The University of Electro-Communications); Yuki Kinoshita (The University of Electro-Communications)*; Nora Schelte (Bochum University of Applied Sciences); Semih Severengiz (Bochum University of Applied Sciences); Tetsuo Yamada (The University of Electro-Communications)

Abstract. In recent years, there has been a call for a shift to transportation with lower greenhouse gas (GHG) emissions in order to combat global warming. One of the ecofriendly transportations is an electric moped scooter (e-moped) sharing service that does not emit GHG when it runs. It is necessary to plan the location of charging stations and the material procurement through the manufacturing of e-mopeds in order to reduce the cost, GHG emissions and improve the accessibility of the service. In this study, two-stage design on the e-moped sharing services is adopted to allocate charging stations and select material suppliers for e-mopeds using integer programming. The method to determine the suitable charging station locations and sizes, and supplier selection are also presented. Numerical experiments are conducted to illustrate the proposed design and analysis method by assuming Kumpan 1954 i model installing in Bochum and Chofu cities. In the numerical experiments, set covering and maximal covering location problems with small coverage radius of charging stations would be better by evaluating accessibility, GHG emissions, and cost comprehensively for Bochum and Chofu cities, respectively. In the supplier selection, a higher GHG reduction target such as 70% reduction would be desired for both cases. The difference of the best scenario in case of Bochum and Chofu cities could be attributed to the different population biases of the two cities.

Keywords: Carbon Neutrality, Product Life Cycle, E-moped Sharing Service, Life Cycle Assessment (LCA), Facility Location Problem, Integer Programming, Supplier Selection

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