# GCSM

## 22nd Global Conference on Sustainable Manufacturing

## Circular Manufacturing for Sustainable Future

**September 23 to 25, 2026**

**Colombo, Sri Lanka**

# CONFERENCE BOOK

Last update: 16.09.26

# Preface

The University of Moratuwa, the Technical University of Berlin (IWF) and Fraunhofer IPK cordially invite you to the 22nd Global Conference on Sustainable Manufacturing (GCSM) at the Cinnamon Lakeside Hotel in Colombo.

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 130 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 the GCSM 2026 in Sri Lanka!

Best regards,

Prof. Dr.-Ing. Günther Seliger, Prof. Dr.-Ing. Holger Kohl, Prof. Dr.-Ing. Franz Dietrich, Prof. Fazleena Badurdeen – International Chairs

Prof. JR Gamage, Dr. Asela K. Kulatunga – National Chairs

Prof. I.S. Jawahir – Honorary Chair

| 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** | **2026** |
| 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 | XXII. GCSM Colombo |

# Committees

**Conference Chairs:**

| | |
|---|---|
| Prof. Dr. -Ing. Holger Kohl | International Chairman |
| Prof. Dr. -Ing. Franz Dietrich | International Chairman |
| Prof. Dr. -Ing. Günther Seliger | International Chairman |
| Prof. Fazleena Badurdeen | International Chairman |
| Prof. I.S. Jawahir | Honorary Chair |
| Prof. JR Gamage | National Chair |
| Dr. Asela Kulatunga | National Chair |

**International Organizing Committee:**

| | |
|---|---|
| Maxim Mintchev | International Organizational Team |
| Felix von Amelunxen | International Organizational Team |
| Jaeheon jung | International Organizational Team |

**National Organizing Committee:**

| | |
|---|---|
| Dr. Lihil Subasinghe | National Organizational Team |
| Dr. Biman Hettiarachchi | National Organizational Team |
| Hiran Rajasuriya | National Organizational Team |
| Ayodhya Darshani | National Organizational Team |
| Hasith Gunasekara | National Organizational Team |

**International Scientific Committee:**

| | |
|---|---|
| Prof. Ahmed Abu Hanieh | Birzeit University |
| Dr. Feri Afrinaldi | ANDALAS UNIVERSITY |
| Prof. Tülin Aktin | İstanbul Kültür Üniversitesi |
| Prof. Elita Amrina | Andalas University |
| Prof. Fazel Ansari | Technische Universität Wien |
| Prof. Antonio Arciénaga | Universidad Nacional de Salta |
| Prof. Fazleena Badurdeen | University of Kentucky |
| Prof. Dirk Bähre | Universität des Saarlandes |
| Prof. Peter Ball | University of York |
| Dr. Pinar Bilge | Technische Universität Berlin |
| Prof. Wahidul Biswas | Curtin University |
| Prof. Friedrich Bleicher | Technische Universität Wien |
| Prof. Dermot Brabazon | Dublin City University |
| Prof. Erhan Budak | Sabancı Üniversitesi |
| Prof. Giampaolo Campana | University of Bologna |
| Prof. Felipe Cerdas | Hochschule für angewandte Wissenschaften Würzburg-Schweinfurt |
| Prof. Jun-Ki Choi | University of Dayton |
| Dr. Roy Damgrave | University of Twente |
| Prof. Wim Dewulf | Katholieke Universiteit Leuven |
| Prof. Sebastián D´Hers | Universidad Torcuato Di Tella |
| Prof. Franz Dietrich | Technische Universität Berlin |
| Prof. Matthew Doolan | Australian National University |
| Prof. Joost Duflou | Katholieke Universiteit Leuven |
| Prof. John Erkoyuncu | Cranfield University |
| Dr. Monica Fabrizio | Italian National Research Council (CNR) |

| | |
|---|---|
| Prof. Matthias Finkbeiner | Technische Universität Berlin |
| Prof. Jörg Franke | Friedrich-Alexander-Universität Erlangen-Nürnberg |
| Prof. Luigi Galantucci | Politecnico Di Bari |
| Dr. Loice K Gudukeya | University of Johannesburg |
| Prof. Karl Haapala | Oregon State University |
| Prof. Michael Zwicky Hauschild | Denmarks Teknise Universitet |
| Prof. Dr. Michael Henke | Fraunhofer-Institut für Materialfluss und Logistik IML |
| Dr.-Ing. Marco Jagodzinski | Technische Universität Berlin |
| Prof. I. S. Jawahir | University of Kentucky |
| Prof. Roland Jochem | Technische Universität Berlin |
| Prof. Stefan Kaierle | Leibniz Universität Hannover |
| Prof. Sami Kara | The University of New South Wales |
| Prof. Takayuki Kataoka | Kindai University |
| Prof. Yusuf Kaynak | Marmara University |
| Dr. Yuki Kinoshita | University of Electro-Communications Tokyo |
| Prof. Thomas Knothe | Fraunhofer IPK |
| Dipl.-Ing. Delf Kober | Technische Universität Berlin |
| Prof. Holger Kohl | Technische Universität Berlin |
| Dr. Philip Koshy | McMaster University |
| Prof. Marwan Khraisheh | Hamad Bin Khalifa University |
| Prof. Jörg Krüger | Technische Universität Berlin |
| Prof. Bernd Kuhlenkötter | Ruhr-Universität Bochum |
| Dr. Asela Kulatunga | University of Exeter, UK |
| Dr. Sze Yin Kwok | RMIT Vietnam |
| Prof. Hoew Pueh Lee | National University of Singapore |
| Dr. Laura V. Lerman | Technical University of Munich |
| Dr. Yongrong Li | SKF Lubrication Systems Germany GmbH |
| Prof. Barbara Linke | University of California, Davis |
| Dr. Raúl Marino | Instituto Tecnológico de Buenos Aires |
| Prof. Muhamad Zameri Mat Saman | Universiti Teknologi Malaysia |
| Prof. Khaled Medini | École des Mines de Saint-Étienne |
| Dr. Robert Mies | Technische Universität Berlin |
| Prof. Hans-Christian Möhring | Universität Stuttgart |
| Prof. Paul Molenda | Hochschule Hof |
| Prof. Laszlo Monostori | Hungarian Academy of Sciences |
| Dr. Úrsula María Montoya Rojo | Instituto Tecnológico de Buenos Aires |
| Prof. Sandra Naomi Morioka | Federal University of Paraíba |
| Prof. Anke Müller | Hochschule Hof |
| Prof. Sebastian Müller | Friedrich-Alexander-Universität Erlangen-Nürnberg |
| Dr. Bernd Muschard | Technische Universität Berlin |
| Dr. Nabil Nasr | Rochester Institute of Technology |
| Dr. Vi Nguyen | Vietnamese German University |
| Dr. Xuan Thanh Nguyen | Vietnamese German University |
| Prof. Marcelo Albuqeurque de Oliveira | Federal University of Amazonas |
| Prof. Mohammed Omar | Khalifa University |
| Dr. Emanuele Pagone | Cranfield University |
| Prof. Salman Pervaiz | Rochester Institute of Technology |
| Prof. Julian Polte | Fraunhofer IPK |
| Dr. Túlio Queijo de Lima | Universidade de São Paulo |
| Prof. Shahin Rahimifard | Loughborough University |
| Dr. Paul Refalo | University of Malta |
| Prof. Michael Rethmeier | Technische Universität Berlin |
| Prof. Christian Rupprecht | Technische Universität Berlin |
| Dr. Konstantinos Salonitis | Cranfield University |
| Prof. Sebastian Schlund | Technische Universität Wien |
| Prof. Matthias Schmidt | Universität Lüneburg |
| Prof. Jan Schmitt | Hochschule für angewandte Wissenschaften Würzburg-Schweinfurt |
| Prof. Günther Seliger | Technische Universität Berlin |

| | |
|---|---|
| Dr. Mustafa Severengiz | Technische Universität Berlin |
| Prof. Semih Severengiz | Hochschule Bochum |
| Dr. Panos Stavropoulos | University of Patras |
| Prof. Frank Straube | Technische Universität Berlin |
| Prof. Henning Strauß | FH Kiel, CIMTT |
| Prof. Nicole Stricker | Hochschule Aalen |
| Prof. Roberto Teti | University of Naples "Federico II" |
| Prof. Sebastian Thiede | University of Twente |
| Dr. Tim van Erp | Flinders University |
| Prof. Thomas Volling | Technische Universität Berlin |
| Dr. Rok Vrabič | University of Ljubljana |
| Prof. Lihui Wang | KTH Royal Institute of Technology |
| Prof. Rafi Wertheim | Technische Universität Chemnitz |
| Prof. Sudhir Yadav | Pandit Deendayal Petroleum University |
| Prof. Tetsuo Yamada | University of Electro-Communications Tokyo |
| Dr. Hitomi Yamaguchi | University of Florida |
| Dr. Shun Yang | Karlsruhe Institute of Technology |
| Prof. Chris Yuan | Case Western University |
| Prof. Michael Zaeh | Technische Universität München |
| Prof. Zhang Weimin | Tongji University |

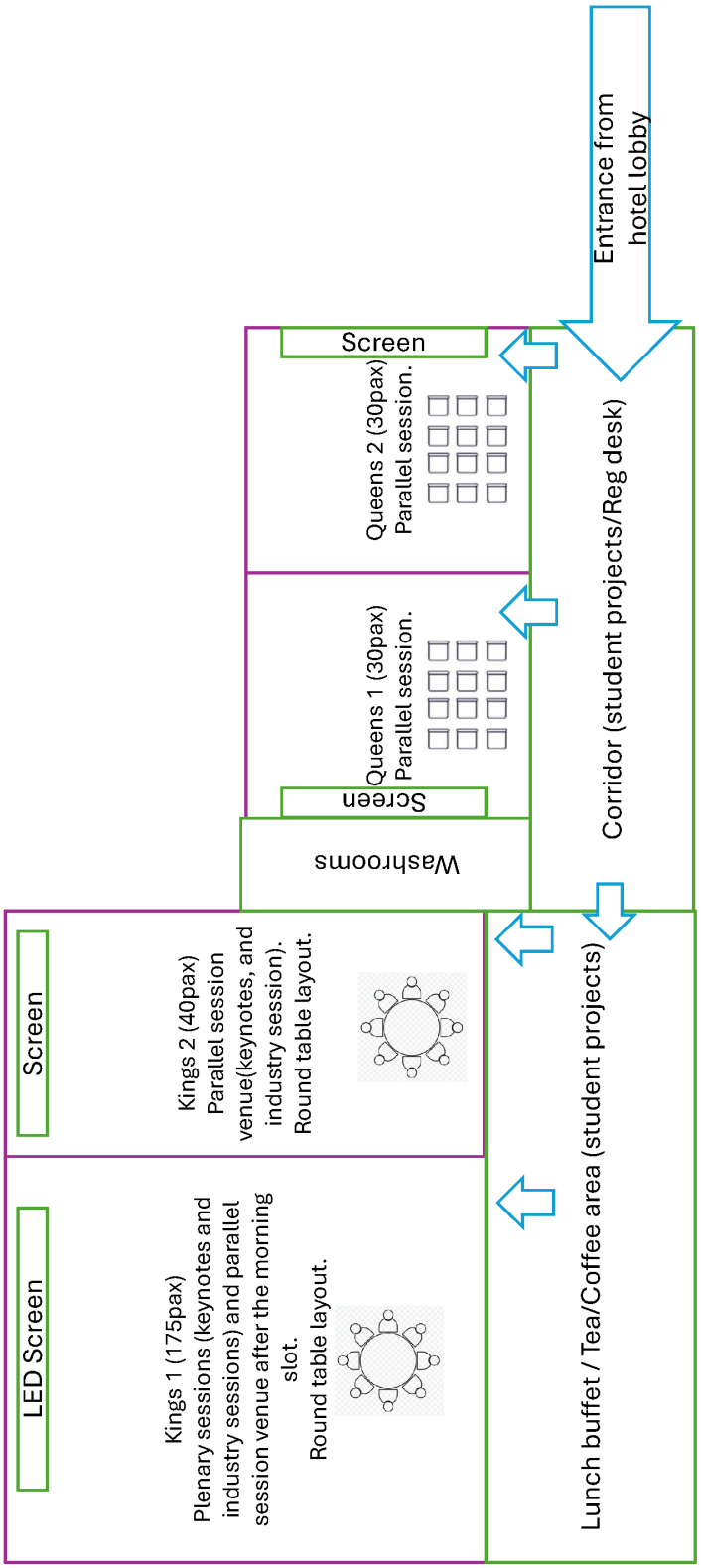
**Local Scientific Committee:**

| | |
|---|---|
| Prof. C.S. Bandara | University of Peradeniya |
| Dr. I.W.N. Bandaranayake | University of Peradeniya |
| Dr. U.S.S. Dharmapriya | University of Peradeniya |
| Prof. JR Gamage | University of Moratuwa |
| Dr. P. Gamage | University of Peradeniya |
| Dr. H.P. Karunathilake | University of Pittsburgh |
| Prof. Migara Liyanage | Sri Lanka Institute of Information Technology |
| Prof. G.I.P. Perera | University of Ruhuna |
| Dr. M. Rathnayake | University of Moratuwa |
| Dr. J. Sudusinghe | University of Moratuwa |
| Dr. K.C. Wickramasinghe | University of Ruhuna |

# Conference Programme

| time\date | September 23, 2026 | | | | September 24, 2026 | | | | September 25, 2026 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 08:00 | Welcome and Registration (8:00–8:30) | | | | Reception (8:00–8:30) | | | | Reception (8:00–8:30) | | | |
| 08:30 | **Conference Opening (8:30–9:05)** | | | | **Keynote Peiris (8:30–8:50)** | | | | **Keynote Biswas (8:30–8:50)** | | | |
| 09:00 | **Keynote Jawa (9:05–9:25)** | | | | **Keynote Kohl (8:50–9:10)** | | | | **Keynote Khraisheh (8:50–9:10)** | | | |
| 09:30 | **Keynote Colledani (9:25–9:45)** | | | | Coffee break (9:10–9:30) | | | | Coffee break (9:10–9:30) | | | |
| 10:00 | Coffee break (9:45–10:00) | | | | **Industry session 1** | **Session 13** Simulation for Circular Manufacturing | **Session 14** Digital Product Passports | **Session 15** Student Session I | **Session 22** Sustainable Manufacturing Systems | **Session 23** Sustainable Business Models | **Session 24** Sustainable Energy Transition and Development | **Session 25** Sustainable Consumer Goods |
| 10:30 | **Session 1** Circular Transformation | **Session 2** Approaches and Models for Sustainable Manufacturing | **Session 3** Automation and Quality Management | **Session 4** Sustainable Regional Development | | | | | | | | |
| 11:00 | | | | | | | | | Farewell and Outlook 2027 (11:30–12:00) | | | |
| 11:30 | | | | | | | | | | | | |
| 12:00 | Lunch break (12:00–13:00) | | | | Lunch break (12:10–13:10) | | | | Lunch break (12:00–13:00) | | | |
| 12:30 | | | | | | | | | | | | |
| 13:00 | **Session 5** Decision Support Systems for Circular Economy | **Session 6** Sustainable Product Design I | **Session 7** Additive Manufacturing | **Session 8** Sustainable Supply Chain | **Industry session 2** | **Session 16** Life Cycle Assessment | **Session 17** Manufacturing Processes I | **Session 18** Student Session II | Company visits | | | |
| 13:30 | | | | | | | | | | | | |
| 14:00 | | | | | | | | | | | | |
| 14:30 | | | | | | | | | | | | |
| 15:00 | Coffee break (15:00–15:15) | | | | Coffee break (15:10–15:25) | | | | | | | |
| 15:30 | **Session 9** Sustainability Assessment | **Session 10** Sustainable Product Design II | **Session 11** Sustainable Assessment of Metal Additive Manufacturing | **Session 12** Optimization for Sustainability | **Industry session 3** | **Session 19** End of Life Approaches | **Session 20** Manufacturing Processes II | **Session 21** Social Sustainability | | | | |
| 16:00 | | | | | | | | | | | | |
| 16:30 | | | | | Bus transfer to Conference Dinner | | | | | | | |
| 17:00 | | | | | | | | | | | | |
| 17:30 | | | | | | | | | | | | |
| 18:00 | | | | | Conference Dinner | | | | | | | |
| 18:30 | | | | | | | | | | | | |

# Venue Map


Entrance from hotel lobby
Corridor (student projects/Reg desk)
Screen
Queens 2 (30pax) Parallel session.
Queens 1 (30pax) Parallel session.
Screen
Washrooms
Screen
Kings 2 (40pax) Parallel session venue(keynotes, and industry session). Round table layout.
LED Screen
Kings 1 (175pax) Plenary sessions (keynotes and industry sessions) and parallel session venue after the morning slot. Round table layout.
Lunch buffet / Tea/Coffee area (student projects)

# Keynotes

## Keynote 1:

**September 23, 2026, 09:05 - 09:25 a.m.**

Prof. I.S. Jawahir

Title: Circular Products, Processes and Systems for Transformative Next Generation Sustainable Manufacturing

*James F. Hardymon Endowed Chair in Manufacturing Systems, University of Kentucky*

**Abstract:**

Sustainable manufacturing, which offers significant environmental, economic and societal benefits, has in recent times emerged globally as a truly transformative and value adding technological platform for accelerated growth and economic development. Closed-loop circular manufacturing which serves as the driver and precursor to sustainable manufacturing, represents three interconnected integral elements of manufacturing: products, processes and systems. This presentation will focus on recently established product circularity principles and the uniquely novel circular manufacturing processes to demonstrate their transformative impact on next generation sustainable manufacturing systems. New opportunities and benefits for implementing a metrics-based product circularity evaluation methodology for concurrent product-process design will be presented. A key aspect of this presentation will be the recent emphasis on developing standards and toolkits for circular product design by various organizations such as ISO, ASTM, EN, UL, etc.

A hierarchical approach involving a comprehensive analysis of the entire manufacturing value chain at component, sub-assembly, assembly and system levels developed from the basis of product and process circularity considerations will be shown in this presentation with applications of product circularity principles for consumer products and industrial systems.

A value proposition for circular manufacturing systems involving four product life-cycle stages (pre-manufacturing, manufacturing, use and post-use) will be discussed with a brief introduction of recently emerged novel production technologies for upcycling of end-of-life products for greater value creation. Case studies demonstrating upcycling methods will be presented for sustainable value creation throughout the entire life-cycle, showing new

opportunities for industrial symbiosis and implementation strategies.

The importance of stakeholder (manufacturer, user and society-at-large) expectations for economic growth and societal wellbeing, and the associated technological challenges involved in meeting their needs through education and training at all levels (high school, undergraduate, graduate and industry levels) will also be presented.

## Keynote 2:

**September 23, 2026, 09:25 - 09:45 a.m.**

Prof. Marcello Colledani

Title: Mobile de-manufacturing and reprocessing systems for local circular manufacturing in urban, peri-urban areas and islands

*Full Professor, Mechanical Engineering Department, Politecnico di Milano, Italy*

**Abstract:**

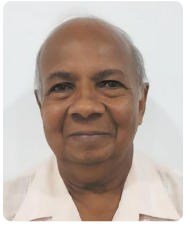
To Be Anounced(TBA)

# Keynote 3:

**September 24, 2026, 08:30 - 08:50 a.m.**

Eng. V. R. Sena Peiris

Title: Enhancing Wealth and Reaching Sustainability through Cleaner Production and Circular Economy



*Chair, National Expert Committee on Climate Change Mitigation, Sri Lanka*

**Abstract:**

The global eco systems are damaged causing escalating pollution while a large portion of the global population in impoverished causing illness and death from hunger in the midst of innovative technological advancement. The central cause for both these global problems is the wasteful use of resources at every stage of human life. The business and industry sector contribute heavily to resource wastage along the entire life cycle of the products leading to pollution and eco system damage leading to fortunes ending up in the drain. Many developed countries have embraced circular economy as the lasting solution for optimization of resource productivity in product manufacturing and services but developing countries are still struggling to manage their waste dumps.

Though circular economy suggests many strategies very little attempt is made to eliminate waste at the point of generation. Cleaner Production approach suggests wastes are resources in a wrong place or wrong form and suggests we should attempt to eliminate waste at the point of generation. Cleaner Production can be used for tracking of wastes generation along a manufacturing process or in a service delivery or can be extended to track waste generation along a life cycle of a product. The three key strategies reduction of waste at source, recovery of resources from wastes and product modification can be expanded in a set of floor level techniques for waste elimination. Extending these strategies can be used to decouple resource use from economic wellbeing and environmental degradation through reduction of resource intensity of products, recovery of resources, redesigning products through eco design and enabling smart consumption by the users. Cleaner Production can be considered as the foundation of Circular Economy as both concepts lead to circular material flows where Cleaner Production facilitates industrial enterprises to approach zero waste generation while Circular Economy strategies can generate economic value for post-consumer wastes by creating many industrial opportunities

through Industrial Symbiosis and Eco innovation. Globally many examples showcase how Cleaner Production and Circular Economy can transform human wasteful culture to a wasteless culture.

## Keynote 4:

**September 24, 2026, 08:50 - 09:10 a.m**

Prof. Dr.-Ing. Holger Kohl

Title: Global aspects for DPP in the context of circular economy

*Professor of Sustainable Corporate Developmentat the Institute for Machine Tools and Factory Management (IWF) at the Technical University of Berlin and Deputy Director of Fraunhofer IPK*

**Abstract:**

Digital Product Passports (DPPs) play a crucial role in strengthening the circular economy by improving the flow of information throughout a product's lifecycle. In particular, digital product passports can close gaps in product information and lifecycle data, facilitate a more circular approach and promote longevity, repair and recycling, and also provide context-sensitive information seamlessly between all stakeholders both in the value chain and after end-of-life.

# Keynote 5:

**September 25, 2026, 08:30 - 08:50 a.m.**

Prof. Wahidul Biswas

Title: Circular Manufacturing: Reshaping Global Production and Resource Use

*Deputy Director, Sustainable Engineering Group, School of Civil and Mechanical Engineering, Curtin University, Australia*

**Abstract:**

There is only one planet earth, but we are now consuming resources 1.8 times faster than the earth can regenerate. As we approach the 21st century, the earth will neither have enough natural resources to sustain population growth nor to manufacture devices indispensable for reducing greenhouse gases to achieve a net-zero emission target. Our economy now is mostly ‘linear’, with the traditional “Take-Make-Use-Dispose” functions. The Global Circularity Gap Report 2026 report explored that the circular gap is still 93%, meaning that a significant portion of the materials that are used to make products to meet the societal demand are raw/virgin materials, and then after use they are thrown away without taking account the recovery of these finite and rapidly depleting resources into product design and manufacturing processes. Circular manufacturing is one of the main pathways to reduce the circular gap as it ensures the manufacture of products of high quality, durability, modular, and performance with improved or enhanced functionality using energy-efficient, non-toxic, low hazard, safe, secure, and affordable technologies and manufacturing methods, and recycled materials, making optimal use of resources and energy and producing minimal wastes and emissions, and providing maximum recovery, recyclability, reusability, remanufacturability, with redesign features, all aimed at enhanced resource efficiency and intergenerational social equity.

# Keynote 6:

**September 25, 2026, 08:50 - 09:10 a.m.**

Prof. Marwan Khraisheh

Title: From End-of-Life to Next Life: Sustainable Manufacturing and Circular Reuse of Thin Film Composite Membranes for Water Security

*Professor and Head, Division of Mechanical and Industrial Engineering, College of Science and Engineering, Hamad Bin Khalifa University, Doha, Qatar*

**Abstract:**

Access to clean water is becoming an increasingly critical global challenge due to population growth, urbanization, industrialization, pollution, and the depletion of conventional freshwater resources. In this context, desalination has become a strategic pillar of water security, with reverse osmosis (RO) emerging as the leading technology because of its high efficiency, modularity, scalability, and comparatively lower energy demand, making it the dominant technology in modern desalination practice.

Yet the success of RO has created a parallel sustainability challenge that has received far less attention: the growing accumulation of end-of-life (EoL) membrane modules. By 2025, global EoL generation is projected to exceed 2 million modules per year, corresponding to more than 33,000 tons of polymer-rich waste. Current EoL practices remain largely rooted in disposal or resource-destructive treatments, resulting in the loss of embedded material value, additional environmental burdens, and are inconsistent with the principles of circular economy and sustainable manufacturing.

The talk emphasizes the perspective that RO membrane modules should no longer be regarded as disposable consumables, but rather as recoverable and remanufacturable products within a circular system. It argues for a transition from replacement-based thinking toward lifecycle extension strategies centered on product recovery, reuse, and sustainable remanufacturing. Within this framework, membrane modules are viewed as high-value engineered products whose structural integrity and residual functionality can be retained and redirected into subsequent service lives.

# Paper Sessions

| Wednesday, September 23rd, 10:00 - 12:00 | | | |
|---|---|---|---|
| **Circular Transformation** | **Approaches and Models for Sustainable Manufacturing** | **Automation and Quality Management** | **Sustainable Regional Development** |
| King's Court I | King's Court II | Queen's Court I | Queen's Court II |
| Advancing Circular Business Model Canvases: Comparative Insights on ISO 59010 Alignment and the Ten Retention Options (ID 47) | A Systemic Maturity Model to Enable Integrative and Sustainable Product–Production System Development (ID 99) | Automated Stitching Control System for Curved Fabric Panels Using Stepper Motor Drive Pulse Mapping (ID 17) | Drinking Water Defluoridation for Off-Grid Areas: A Compact and Energy-Efficient CNT-MCDI System (ID 193) |
| Shifting Value Capture in Circular Business Models: Evidence from a Multiple-Case Study (ID 4) | Defining Lifecycle Management Requirements across the Process Lifecycle of Sustainable Manufacturing-as-a-Service Platforms (ID 128) | Order-Closing Strategies for Picking Efficiency and Environmental Sustainability in an Autonomous Mobile Robots (AMR) Material Handling System (ID 121) | Climate Resilient Salt Production in Sri Lanka: A Techno-Economic Analysis of Pure Vacuum Dried (PVD) Salt Manufacturing (ID 138) |
| Sustainability and circular economy – Insights from SMEs in the Danish-German border region (ID 114) | Machine retrofitting for a sustainable industrial future: relevance, evolution, and integration with Industry 4.0 and Industry 5.0 (ID 28) | YOLOv8-Based Computer Vision for Automated Crate Inspection in High-Speed Beverage Bottling Lines: Model Training, Validation, and Deployment Analysis (ID 68) | Transitioning to Battery Electric Light Rail for Sustainable Transport (ID 177) |
| Framework for the configuration of global production networks in an Upgrade Circular Economy (ID 65) | Microenvironments for Battery Manufacturing: Functional Design and Dew-Point Energy Assessment (ID 58) | AI-driven Quality Management System for Circular Textile Waste Management (ID 151) | Validating a Model of Sustainable Manufacturing in Shared Urban Infrastructures (ID 184) |
| Transforming Process Landscapes for Re-Assembly: A Strategic Business Process Management Perspective (ID 129) | Production lot-specific allocation of energy demand using data mining on machine tool load profiles (ID 43) | Visual Quality Score Assessment of Large White Goods in Remanufacture with Multi-View Deformable-DETR (ID 25) | |
| Conceptual methodology for assessing the advancement from repair to remanufacturing (ID 78) | Reconfiguring a Global Medical Technology Company: Enhancing Performance in Global Process Engineering for Industry 4.0 and Sustainable Manufacturing (ID 75) | Decision Support for Metal Repair Process Chains in Circular Manufacturing: A Literature-Based Reference Model and Multi-Criteria Workflow (ID 205) | |

# Circular Transformation
# Wednesday, September 23rd, 10:00 - 12:00

## King's Court I

### Advancing Circular Business Model Canvases: Comparative Insights on ISO 59010 Alignment and the Ten Retention Options
**(ID 47)**

Jonas Mohnke (Institute of Product Engineering, Saarland University), Michael Vielhaber (Institute of Product Engineering, Saarland University)

*Presenting Author:* Jonas Mohnke (Institute of Product Engineering, Saarland University)

**Abstract**. The transition toward a circular economy requires systematic business approaches that integrate product development and value creation while aligning with frameworks such as ISO 59010 and the ten retention options. The Business Model Canvas, consisting of nine building blocks, is a widely established tool for business model development and innovation, with numerous extensions developed to incorporate circularity and sustainability dimension. However, this diversity complicates their selection and practical application. To address this, the study conducts an exploratory literature review, resulting in a comparative analysis, of business model canvases to grant an overview and examine their shared features and divergences to determine the methodological developments necessary for compliance with ISO 59010. First, canvases are assessed using general criteria, including complexity, practical applicability, and circularity. Second, their alignment with circular economy paradigms is analyzed based on the ten retention options. A key finding is the imbalance in strategy coverage, with slowing strategies widely addressed, while narrowing and certain closing strategies remain underrepresented. Furthermore, most circular canvases provide limited decision support and insufficient integration of external conditions. The paper concludes by calling for an integrated, methodologically guided circular canvas approach that systematically includes all retention options.

### Shifting Value Capture in Circular Business Models: Evidence from a Multiple-Case Study
**(ID 4)**

Marcel Fischer (Institute for Production Management, Technology and Machine Tools (PTW)), Stefan Sailer (Lorenz GmbH & Co.KG), Dietmar Grimm (Lorenz GmbH & Co.KG), Daniel Ditterich (Festo SE & Co. KG), Victoria Pohl (Festo SE & Co. KG), Enno Lang (Institute for Production Management, Technology and Machine Tools (PTW)), Joachim Metternich (Institute for Production Management, Technology and Machine Tools (PTW))

*Presenting Author:* Marcel Fischer (Institute for Production Management, Technology and Machine Tools (PTW))

**Abstract**. The transition to a circular economy is widely regarded as a promising approach to fostering sustainable economic practices. However, a major challenge lies in its limited implementation in industrial practice. Accelerating this transition requires a deeper understanding of how production-related circular business models affect established linear value capture structures. This paper addresses this issue by analyzing and quantitatively assessing three practical remanufacturing business model approaches and examining their impact on manufacturing firms' cost structures. The findings indicate an increasing emphasis on the later stages of the product life cycle. Thus, end-of-life activities like product take-back and reconditioning gain importance, whereas early phases, including procurement and production, lose significance. This leads to substantial changes in the cost structures of manufacturing firms, thereby increasing complexity. By highlighting and quantifying these changes, this paper advances the understanding of remanufacturing business models and their economic assessment.

**Sustainability and circular economy – Insights from SMEs in the Danish-German border region (ID 114)**

Marcus Brandenburg (Flensburg University of Applied Sciences)

*Presenting Author:* Marcus Brandenburg (Flensburg University of Applied Sciences)

**Abstract**. This work summarizes results of empirical studies on practices, prerequisites and performance impacts of sustainability and the circular economy (CE). A CE reference model and practical guidelines for sustainability management and CE are presented. In addition, related barriers, enablers, incentives and risks of CE application are tackled and implementation guidelines are given. This may help decision-makers and policy-makers to manage sustainability and CE. Insights were gained between April 2023 and March 2026 in a larger knowledge transfer project that supports the transition towards sustainability and CE in small and medium-sized enterprises (SMEs) of the German-Danish border region. Data were collected empirically by expert interviews and surveys, analyzed qualitatively and validated and evaluated in a way that addresses researchers and practitioners alike. Findings and conclusions of the studies were disseminated in workshops and conferences and by written reports. The results can be transferred to other contexts in scientific research and management practice.

**Framework for the configuration of global production networks in an Upgrade Circular Economy (ID 65)**

Thilo Walter (Laboratory for Machine Tools and Production Engineering (WZL), RWTH Aachen University), Günther Schuh (Laboratory for Machine Tools and Production Engineering (WZL), RWTH Aachen University), Benedict Janssen (Laboratory for Machine Tools and Production Engineering (WZL), RWTH Aachen University), Tim Hommen (Laboratory for Machine Tools and Production Engineering (WZL), RWTH Aachen University)

*Presenting Author:* Thilo Walter (RWTH Aachen University)

**Abstract**. The transition from a linear towards an Upgrade Circular Economy extends Circular Economy Principles through value-preserving product upgrades during post-return reprocessing. This transition requires the systematic integration of Reverse Logistics and reprocessing into existing Global Production Networks. Due to established structural and resource constraints in Global Production Networks, such transitions pose a significant challenge for industry. At the same time, these constraints can be leveraged as a basis for identifying process- and resource-based synergy potentials within existing network configurations. Despite its relevance for sustainable manufacturing, the configuration of Global Production Networks to enable an Upgrade Circular Economy remains insufficiently addressed, particularly with respect to systematic configuration approaches for existing networks. To address this gap, this paper proposes a framework structured into three modules. While the first module describes the solution space for network configurations in an Upgrade Circular Economy, the second module focuses on evaluating alternative network configuration options. It integrates a similarity assessment and a gap analysis based on the comparison of process clusters with the existing network configuration to enable structured and transparent identification of required site-specific adaptations. Finally, the framework is embedded in a procedural approach for the configuration of production networks in an Upgrade Circular Economy.

**Transforming Process Landscapes for Re-Assembly: A Strategic Business Process Management Perspective (ID 129)**

Friedrich Wintzer (Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University), Günther Schuh (Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University, Fraunhofer Institute for Production Technology IPT), Tim Hommen (Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University), Benedict Janssen (Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University)

*Presenting Author:* Friedrich Wintzer (RWTH Aachen University)

**Abstract**. Increasing volatility in global supply chains and constrained availability of virgin materials are intensifying the need for resource-efficient production and usage. Re-Assembly is a specialized form of remanufacturing that additionally enables the systematic reuse of recovered components in new product configurations. It temporally decouples recovery and reassembly, supports cross-product component reuse, and facilitates the integration of technological and design upgrades, thereby renewing product lifecycles while reducing resource consumption. Compared to linear manufacturing, it represents a fundamentally different mode of value creation and therefore affects not only production activities but also support and management processes across the process landscape. As a result, the transition to Re-Assembly becomes difficult to plan, as companies lack transparency regarding the scope and interdependencies of the required organizational adjustments. This paper investigates how transformation needs in process landscapes can be identified and structured when introducing Re-Assembly. Building on an established framework of strategic business process management, a business process model adapted to the requirements of Re-Assembly is developed. Identified transformation requirements are classified according to their process category and transformation type. The study provides a structured basis for aligning organizational processes with the requirements of Re-Assembly.

**Conceptual methodology for assessing the advancement from repair to remanufacturing (ID 78)**

Moritz Eichmann (Technical University of Munich, School of Engineering and Design, Institute for Machine Tools and Industrial Management (iwb)), German Bluvstein (Technical University of Munich, School of Engineering and Design, Institute for Machine Tools and Industrial Management (iwb)), Maximilian Lechner (Technical University of Munich, School of Engineering and Design, Institute for Machine Tools and Industrial Management (iwb)), Christina Reuter (Technical University of Munich, School of Engineering and Design, Institute for Machine Tools and Industrial Management (iwb))

*Presenting Author:* Moritz Eichmann (Technical University of Munich)

**Abstract**. Remanufacturing offers ecological and economic potential by reusing products and components, thereby reducing material and energy consumption. However, the implementation poses numerous challenges, hindering adoption in practice. One viable pathway is building remanufacturing on existing repair services. Firms advanced in repair hold advantages in process expertise, infrastructure, and product design requirements for advancing to remanufacturing. However, such advancements entail uncertainties that affect costs and benefits, making it difficult in practice to evaluate them in both economic and ecological terms. Nonetheless, scientific contributions that systematically address the advancement from repair to remanufacturing and enable a structured assessment to support decision-making for this transition are lacking. This paper aims to close this research gap by proposing a three-module conceptual methodology that assesses the economic and ecological viability of advancing from repair to remanufacturing at the company level. Module I provides a requirements analysis of repair and remanufacturing. Module II introduces a qualitative method that enables companies to identify the conditions required for the transition. Module III presents a quantitative method that supports investment decisions by accounting for uncertainties. The proposed concept has the potential to support manufacturing companies in evaluating this transition and facilitate informed, company-specific investment decisions.

# Approaches and Models for Sustainable Manufacturing
# Wednesday, September 23rd, 10:00 - 12:00

## King's Court II

### A Systemic Maturity Model to Enable Integrative and Sustainable Product–Production System Development (ID 99)

Jan-Philipp Disselkamp (Fraunhofer IEM), Ben Schütte (Fraunhofer IEM), Tobias Seidenberg (Fraunhofer IEM), Fiona Kattenstroth (Fraunhofer IEM), Ralf Schlosser (Jade University of Applied Science), Roman Dumitrescu (University Paderborn – HNI)

*Presenting Author:* Ralf Schlosser (Jade University of Applied Science)

**Abstract**. The transition toward sustainable manufacturing requires production systems that are energy-efficient, resource-conscious, and capable of supporting circular product strategies. At the same time, increasing product complexity and digitalization demand closer integration between product development and production system design. In industrial practice, however, both domains are still largely organized sequentially, often leading to late design changes, inefficient resource utilization, and suboptimal life-cycle performance. Although integrative product and production system development (IPP) has been widely discussed in research, companies still lack structured capability development frameworks that enable stepwise and risk-controlled implementation. In particular, the transformation toward sustainable manufacturing requires transparent assessment methods, data-based prioritization, and coordinated improvement roadmaps. This paper extends an existing maturity model for Integrative Product and Production System Development (IPPS) by introducing an impact-based prioritization mechanism. Building on previous work, the approach analyzes interdependencies between action elements and uses pairwise interaction analysis to determine relative impact strengths. Pairwise interaction analysis is used to determine relative impact strengths, enabling companies to identify high-leverage improvement measures that enhance overall system performance and resource efficiency.

### Defining Lifecycle Management Requirements across the Process Lifecycle of Sustainable Manufacturing-as-a-Service Platforms (ID 128)

Maurice Meyer (Chair of Quality Science, Technical University of Berlin), Götz Müller (Chair of Quality Science, Technical University of Berlin), Viviane Sarwar (Chair of Quality Science, Technical University of Berlin), Luong Le (Chair of Quality Science, Technical University of Berlin), Roland Jochem (Chair of Quality Science, Technical University of Berlin)

*Presenting Author:* Maurice Meyer (TU Berlin)

**Abstract**. Platform-based models such as Manufacturing-as-a-Service (MaaS) offer new opportunities for adaptive and resource-conscious production. Likewise, ensuring sustainable and effective operation of MaaS platforms requires a systematic understanding of Lifecycle Management (LCM). This paper therefore focuses on identifying, categorizing and evaluating LCM requirements for digital MaaS platforms to support sustainability and circularity in networked production. To this end, a descriptive research approach was adopted, combining a literature review with structured clustering and mapping of requirements to lifecycle phases. The study synthesizes general LCM requirements and translates them into MaaS-specific needs across the process lifecycle, from resources to end-of-life decommissioning. The results provide a comprehensive set of LCM requirements tailored to MaaS environments, emphasizing data integration, traceability and adaptive decision-making. Building on these findings, the derived requirements form the basis for developing a MaaS-specific LCM approach to guide the sustainable design and operation of platform-based manufacturing ecosystems.

**Machine retrofitting for a sustainable industrial future: relevance, evolution, and integration with Industry 4.0 and Industry 5.0**
**(ID 28)**

Vanessa Traut (Institute of Production Engineering, Saarland University), Michael Vielhaber (Institute of Product Engineering, Saarland University), Dirk Bähre (Institute of Production Engineering, Saarland University)

*Presenting Author:* Vanessa Traut (Universität des Saarlandes Lehrstuhl für Fertigungstechnik)

**Abstract**. Nowadays, the need to comply with evolving industrial standards confronts industrial manufacturing processes with the challenge of rapid technological advancements while operating ageing machinery. At the same time, the increasing pressure to improve sustainability due to resource scarcity and environmental concerns, as well as legal requirements, initiates rethinking on the manufacturing process. Furthermore, the demanding integration of digital technologies and human-centric approaches of Industry 4.0 and emerging Industry 5.0 paradigms need to be considered in this matter. In this context, machine retrofitting has emerged as a potential strategy to extend the lifetime of existing equipment while enabling sustainable and digital transformation. This paper reviews and synthesizes existing research to assess the relevance of machine retrofitting for a sustainable industrial future. The review evaluates how traditional and smart retrofitting, as well as revamping and remanufacturing, are defined in the literature, highlighting their conceptual distinctions and practical implications. Furthermore, it evaluates the contribution of machine retrofitting to environmental, economic, and social sustainability in industrial systems and analyses its role within Industry 4.0 and emerging Industry 5.0 frameworks. The information gathered will be used to develop a conceptual successive framework to endorse the inspected requirements.

**Microenvironments for Battery Manufacturing: Functional Design and Dew-Point Energy Assessment**
**(ID 58)**

Jan-Niklas Sturm (wbk Institute of Production Science - Karlsruhe Institute of Technology (KIT)), Onur Tokmak (Exentec Germany GmbH Cleanroom & Dryroom), Darien Massagli (Exentec Germany GmbH Cleanroom & Dryroom), Sebastian Henschel (wbk Institute of Production Science - Karlsruhe Institute of Technology (KIT)), Jürgen Fleischer (wbk Institute of Production Science - Karlsruhe Institute of Technology (KIT))

*Presenting Author:* Jan-Niklas Sturm (wbk – Insitute of Production Science at Karlsruhe Institute of Technology KIT)

**Abstract**. Lithium-ion battery manufacturing requires very dry environmental conditions for moisture-sensitive process steps, which are commonly provided by large-scale dry rooms with high HVAC (Heating, Ventilation, and Air Conditioning) demand. Microenvironments offer an alternative by localizing the conditioned atmosphere to the immediate process space and can thereby reduce both conditioned volume and moisture loads caused by leakage and air exchange during human access periods. This paper presents the redesign and experimental benchmark of a microenvironment for battery manufacturing. A previously realized reference concept from the AgiloBat project is compared with a redesigned concept developed in the InMicroBatt context. The redesign was guided by the objective of reducing climatic and energetic effort while preserving the required operational and maintenance accessibility. The experimental evaluation addresses startup behavior, steady-state operation, and a maintenance-related intervention scenario with operator presence. Dew-point behavior was assessed using internal process measurements and validated against chilled-mirror hygrometry, while electrical power demand was recorded continuously. The study demonstrates the potential of redesigned microenvironment concepts as compact and energy-efficient climate-controlled units for battery production.

**Production lot-specific allocation of energy demand using data mining on machine tool load profiles (ID 43)**

Andreas Wächter (Technical University of Darmstadt, Institute for Production Management, Technology and Machine Tools (PTW)), Ivan Uzunov (Technical University of Darmstadt, Institute for Production Management, Technology and Machine Tools (PTW))

*Presenting Author:* Andreas Wächter (PTW TU Darmstadt)

**Abstract**. The product-specific allocation of energy consumption in industrial manufacturing is a key prerequisite for improving energy efficiency and reducing energy costs. Creating transparency enables the systematic identification of efficiency potentials and supports the targeted implementation of improvement measures and investments. In industrial practice, energy data linked to specific production lots is often not available. In particular, in production systems with existing machine parks that vary in age, origin, technological maturity and data structures, linking process information and energy data is often not easy to implement. To address these limitations, this paper proposes and evaluates a data mining–based approach to extract the processing times of specific production lots from load profiles and assign the energy demand to the respective machining operations. In the proposed approach, the electrical load profile is segmented into subsequences that correspond to the machining of individual workpieces. It is shown that the subsequences can be represented by statistical features and that similar and dissimilar machining operations can be distinguished using density-based clustering. The resulting clusters are mapped to production lots by solving an assignment problem. The approach is experimentally evaluated. The data mining–based time intervals for processing individual lots agree with MES data by 86.1%, while the assigned energy demands match on average by 91.9%.

**Reconfiguring a Global Medical Technology Company: Enhancing Performance in Global Process Engineering for Industry 4.0 and Sustainable Manufacturing (ID 75)**

Daniel Wörner (Institute for Production and Supply Chain Management, University of St.Gallen), Louis Meyer (Institute for Production and Supply Chain Management, University of St.Gallen), Lukas Budde (Institute for Production and Supply Chain Management, University of St.Gallen), Thomas Friedli (Institute for Production and Supply Chain Management, University of St.Gallen)

*Presenting Author:* Daniel Wörner (University of St.Gallen)

**Abstract**. Global production networks in regulated industries face mounting pressure to accelerate Industry 4.0 adoption and sustainable manufacturing while maintaining operational performance. Engineering functions sit at the center of this challenge, yet many companies struggle to coordinate expertise effectively, standardize practices without undermining local responsiveness, and scale innovations beyond isolated pilots. Drawing on a single-case study of a global medical technology company, we combine internal document analysis, four on-site workshops, and ten semi-structured interviews across global and local roles, analyzed using the Gioia methodology. The study reveals five structural barriers forming a cascading sequence: (1) insufficient engineering role model clarity, (2) limited visibility and accessibility of competencies, (3) high reliance on informal relationships, (4) weak central-local integration driven by authority and resource tensions, and (5) significant pilot-to-rollout barriers slowing innovation diffusion. In response, we develop a Sequential Lever Model of three sequentially dependent levers, Role Model Clarity, Cross-Site Coordination Effectiveness, and Central-Local Integration, activated through four moderating mechanisms enabling network-wide scaling of Industry 4.0 and sustainable manufacturing improvements within the studied global production networks. Future research should extend the model across multiple companies and non-regulated environments.

# Automation and Quality Management
# Wednesday, September 23rd, 10:00 - 12:00

## Queen's Court I

### Automated Stitching Control System for Curved Fabric Panels Using Stepper Motor Drive Pulse Mapping (ID 17)

Shenal Fernando (University of Moratuwa)

*Presenting Author:* Shenal Fernando (University of Moratuwa)

**Abstract**. Conventional industrial sewing machines operate at constant fabric feed rates, which limits their ability to produce uniform stitch spacing when sewing complex curved seams. Manual operation leads to in material waste, rework, and reduced production efficiency in high-volume garment manufacturing. To address this, an industrial automation system has been developed to implement the automated stitching of curved fabric panels. A critical aspect of the proposed system involves generating appropriate feed motor path mapping and speed profile. The study identifies that linear alignment between the motor axis and sewing needle results in fabric curve offset along the motor path trajectory. In offset curve generation, the primary challenge is loop intersections arising from curvature radius variation through the curve. To address this challenge, the study proposes an efficient offset curve generation algorithm for 2D point sequence curves with line segments in the stepper motor path trajectory by smoothening the fabric curve. The algorithm is implemented on a physical stitching system, and experimental results demonstrate stable fabric feeding and improved stitch uniformity. By minimizing material waste, lowering rework rates, and improving process repeatability, the proposed approach advances resource efficient and sustainable sewing automation in garment manufacturing.

### Order-Closing Strategies for Picking Efficiency and Environmental Sustainability in an Autonomous Mobile Robots (AMR) Material Handling System (ID 121)

Beatrice Lupi (Department of Industrial Engineering, Alma Mater Studiorum Università di Bologna), Riccardo Accorsi (Department of Industrial Engineering, Alma Mater Studiorum Università di Bologna), Giovanni Ceroni (Department of Industrial Engineering, Alma Mater Studiorum Università di Bologna), Riccardo Manzini (Department of Industrial Engineering, Alma Mater Studiorum Università di Bologna), Marco Ricci (Department of Industrial Engineering, Alma Mater Studiorum Università di Bologna)

*Presenting Author:* Beatrice Lupi (Alma Mater Studiorum - Università di Bologna)

**Abstract**. This study investigates the application of order closing (OC) strategies for picking task assignment in an AMR-based automated material handling system, assessing both operational performance and environmental sustainability. The analysis employs a hybrid simulative methodology that integrates discrete-event modeling with a dynamic interactive framework to reproduce the adaptive behavior of picking operations in a fresh produce distribution system. The proposed approach relies on a rank-based hierarchical model grounded on the OC index introduced by Bartholdi and Hackman (2019), which dynamically prioritizes unit loads that contribute most to the completion of incoming and work-in-progress orders, enabling real-time task dispatching among multiple picking stations served by Autonomous Mobile Robots (AMRs). The simulated scenarios compare OC-based pallet sequencing with a traditional chronological dispatching policy under different AMR allocation and routing configurations, supporting the evaluation of system performance that includes environmental metrics. Results show that the OC-based assignment significantly improves system performance by increasing throughput and improving unit load handling efficiency. Finally, a comparative environmental assessment of AMR fleet sizing across multiple scenarios highlights the trade-off between operational and environmental sustainability performance.

**YOLOv8-Based Computer Vision for Automated Crate Inspection in High-Speed Beverage Bottling Lines: Model Training, Validation, and Deployment Analysis**
**(ID 68)**

B. Chimuso (Department of Industrial and Mechatronics Engineering, University of Zimbabwe), A. Musarurwa (Department of Industrial and Mechatronics Engineering, University of Zimbabwe), L. Gudukeya (Department of Industrial and Mechatronics Engineering, University of Zimbabwe)

*Presenting Author:* Not yet updated

**Abstract**. Manual and sensor-based crate inspection systems in beverage bottling lines suffer from inconsistent detection, false rejection rates exceeding 10%, and high labour intensity. This study presents the design, training, systematic validation, and deployment analysis of a YOLOv8n-based computer vision model for automated full-crate inspection, developed in the context of high-speed production environments typical of beverage manufacturers in sub-Saharan Africa. A dataset of 150 images of filled and partial crates was collected under controlled laboratory conditions replicating bottling-line illumination and camera geometry, then augmented to 900 images via six geometric and photometric techniques using the Albumentations library. The YOLOv8n model (3.2 M parameters) was trained for 100 epochs on Google Colab Pro, achieving precision 0.991, recall 0.968, F1 0.979, and mAP@0.5 of 0.985 at the deployment-optimal confidence threshold of 0.6. A systematic confidence threshold sensitivity sweep (0.1–0.9) identified threshold 0.6 as the Pareto-optimal operating point, reducing false positive rate to 1.2% (from 3.7% at the default 0.25) while maintaining false negative rate below 3.5%. Crate-level classification accuracy on the 90-image test set was 100%. Offline inference benchmarking on an NVIDIA RTX 3060 yielded 101.5 ms per image (30.4 ms forward pass, 70.5 ms NMS postprocessing), projecting to a throughput of 11,800 crates per hour — 7.9 times the representative 1,500 crates/hour bottling line requirement. The work contributes a replicable deep-learning inspection methodology for quality control automation in resource-constrained manufacturing settings, demonstrates that high-accuracy detection is achievable with modest augmented datasets, and provides a systematic threshold selection framework suited to the asymmetric cost structure of industrial inspection.

**AI-driven Quality Management System for Circular Textile Waste Management**
**(ID 151)**

V.P Peramunage (Department of Mechanical Engineering, University of Peradeniya), D.A.A.C. Ratnaweera (Department of Mechanical Engineering, University of Peradeniya)

*Presenting Author:* Vihan Peramunage (Faculty of Engineering, University of Peradeniya)

**Abstract**. The shift towards a circular economy in the global textile industry is limited by manual waste sorting, which is slow and inconsistent. This paper presents an automated, Artificial intelligence (AI) driven quality management system to sort pre-consumer textile waste for reuse, recycling, or downgrading. The system uses a novel multi-modal approach with three machine learning models. A YOLOv8 model finds physical defects, an EfficientNetV2 model classifies fabric color, and a 1D Convolutional Neural Network (1D CNN) uses Near-infrared (NIR) data to find fiber composition. A Fuzzy Inference System (FIS) combines these outputs, acting as the decision engine to calculate a final percentage score for Reusability, Recyclability, and downgrading. The developed prototype achieved high accuracy: the YOLOv8 model reached a mean Average Precision of 81.6%, the EfficientNetV2 model had an 84.38% test accuracy, and the 1D CNN showed strong predictive power when combined with Principal Component Analysis (PCA). This automated system provides a more accurate and consistent assessment. It helps recover valuable resources, supporting a more sustainable and circular textile industry.

**Visual Quality Score Assessment of Large White Goods in Remanufacture with Multi-View Deformable-DETR**
**(ID 25)**

Paul Koch (Fraunhofer-Institut für Produktionsanlagen und Konstruktionstechnik (IPK)), Vivek Chavan (Fraunhofer-Institut für Produktionsanlagen und Konstruktionstechnik (IPK))

*Presenting Author:* Paul Koch (Fraunhofer Institute for Production Systems and Design Technology IPK)

**Abstract**. Remanufacturing large white goods is essential for a circular economy, yet visual quality assessment remains a manual bottleneck for training and pricing. Conventional detection methods require extensive annotation and struggle with small defects in high-resolution multi-view data. We present a multi-view framework based on Deformable-DETR for automated quality scoring that aggregates information across redundant views to extract fine-grained features. To enhance robustness with limited labels, we employ self-supervised pretraining followed by supervised fine-tuning on expert-annotated scores. Additionally, a linear projection over frozen feature maps identifies regions of interest to explain model decisions. Evaluated on an industrial multi-view dataset, our approach delivers precise quality assessments while reducing reliance on manual annotation and per-part customization, enabling scalable and transparent inspection for remanufacturing lines.

**Decision Support for Metal Repair Process Chains in Circular Manufacturing: A Literature-Based Reference Model and Multi-Criteria Workflow**
**(ID 205)**

Maria Grazia Guerra (Politecnico di Bari, Dipartimento di Meccanica, Matematica e Management), Marco Mazzarisi (Politecnico di Bari, Dipartimento di Meccanica, Matematica e Management), Alessandro Pellegrini (University of Foggia, Department of Agriculture, Food, Natural Resources and Engineering), Fulvio Lavecchia (Politecnico di Bari, Dipartimento di Meccanica, Matematica e Management), Sabina Luisa Campanelli (Politecnico di Bari, Dipartimento di Meccanica, Matematica e Management), Luigi Maria Galantucci (Politecnico di Bari, Dipartimento di Meccanica, Matematica e Management)

*Presenting Author:* Luigi Maria Galantucci (Politecnico di Bari, Dipartimento di Meccanica, Matematica e Management)

**Abstract**. Repair of worn or damaged components is a topic of growing interest, as it strongly supports the circular economy paradigm and a more efficient use of resources. Although its advantages over replacement are widely recognized, industrial uptake remains limited by the complexity and non-uniqueness of repair process chains. Based on a literature analysis, this work first decomposes the repair problem into recurring macro-steps, decision gates, interface issues, and cross-step dependencies. Building on this conceptual basis, the main contribution of the paper is the proposal of a decision-oriented reference framework in which repair planning is interpreted as the configuration of an integrated process chain rather than the isolated selection of individual technologies. On this basis, the paper introduces a dual-view multilayer architecture and a priority-driven workflow for comparing candidate repair-chain configurations under feasibility constraints and competing technological, economic, and sustainability priorities. The proposed framework provides a structured basis for more transparent and repeatable repair planning and for future decision-support developments.

# Sustainable Regional Development
# Wednesday, September 23rd, 10:00 - 12:00

## Queen's Court II

### Drinking Water Defluoridation for Off-Grid Areas: A Compact and Energy-Efficient CNT-MCDI System (ID 193)

Wonjin Kim (Seoul National University), Hyunbin Cho (Seoul National University), Sung-Hoon Ahn (Seoul National University)

*Presenting Author:* Hyunbin Cho (Seoul National University)

**Abstract**. Access to safe drinking water is a critical global challenge. High fluoride concentrations in groundwater pose significant health risks in off-grid regions where conventional energy-intensive purification is impractical. This study presents a compact Membrane Capacitive Deionization (MCDI) system using a free-standing carbon nanotube (CNT) film as a multifunctional electrode platform. By integrating activated carbon (AC) onto a conductive CNT substrate via a scalable doctor-blade coating and cold-press bonding process, we developed a hierarchical electrode that simultaneously functions as a current collector and active adsorption layer, minimizing interfacial resistance while reducing system weight and volume. Multi-stage batch experiments starting from an initial fluoride concentration of 9.83 mg/L demonstrated a total removal efficiency of 91.5%, reducing the effluent to 0.83 mg/L—well below the WHO guideline of 1.5 mg/L. The cumulative salt adsorption capacity (SAC) reached 4.53 mg/g with a specific energy consumption (SEC) of only 0.034 kWh/m3. These results establish the CNT-MCDI system as a practical, low-energy technology for decentralized defluoridation in resource-constrained settings.

### Climate Resilient Salt Production in Sri Lanka: A Techno-Economic Analysis of Pure Vacuum Dried (PVD) Salt Manufacturing (ID 138)

Dilantha Thushara (Department of Chemical and Process Engineering, University of Moratuwa), Achini Liyanage (Department of Chemical and Process Engineering, University of Moratuwa), Damidu Disanayake (Department of Chemical and Process Engineering, University of Moratuwa), Kasun Dhananjaya (Department of Chemical and Process Engineering, University of Moratuwa)

*Presenting Author:* Achini Liyanage (University of Moratuwa)

**Abstract**. Traditional solar salterns in Sri Lanka have typically produced around 140,000 MT salt annually meeting the domestic salt demands, but during recent years, salterns have continuously faced interruptions due to highly unpredictable weather patterns. Extreme and long rainy seasons have severely compromised national salt yield by 40% and affected supply chain stability. Since open evaporation ponds are highly susceptible to weather fluctuations, there is an urgent need in transition toward climate resilient manufacturing processes. This study presents a comprehensive techno-economic analysis of integrating Pure Vacuum Dried (PVD) systems into the Sri Lankan salt industry to ensure continuous, weather independent salt manufacturing. The evaluation has analyzed the adaptation of MEE and MVR systems for uninterrupted salt manufacturing throughout the year, followed by a detailed economic assessment. The MEE system was shown to require a CAPEX of $1,684,000 USD with a payback period of 2.3 years, while the MVR system with $2,682,000 USD CAPEX demonstrated a lower operating cost with a stronger cash flow and a payback period of 3.4 years. Both systems established economic viability from the second year of operation. The findings of the study provide a strategic and quantitative roadmap for the Sri Lankan salt industry towards sustainable, energy-efficient, and weather-independent manufacturing.

**Transitioning to Battery Electric Light Rail for Sustainable Transport**
**(ID 177)**

H.K.K. Kasuntha Madhumal (Chief Mechanical Engineer Office, Department of Sri Lanka Railways, Department of Mechanical Engineering, University of Moratuwa), L.U. Subasinghe (Department of Mechanical Engineering, University of Moratuwa), J.R. Gamage (Department of Mechanical Engineering, University of Moratuwa)

*Presenting Author:* Kasuntha Madhumal (Department of Railways)

**Abstract**. Global rail systems are at different stages of electrification. Many European rail networks exceed 60–70% electrification; this is common in other developed regions as well. Meanwhile diesel locomotives are widely used in developing regions for rural services. Low passenger demand and close station spacing are common in these diesel-dominated operations, leading towards low energy efficiency, high emissions, and substantial maintenance costs. This study evaluates the technical, environmental, and economic feasibilities of converting a diesel-electric locomotive into a Battery Electric Light Rail (BELR) for regional passenger transport. A case study of a 45 km-long journey was used for the analysis. Using operational field data and relevant assumptions, a conceptual battery-electric powertrain was developed. The analysis indicates that a 420.8 kWh Lithium Iron Phosphate (LFP) battery system supported by dual 841.6 kW ultra-fast charging stations can fulfil the operational requirements. Over an eight-year operating period, the proposed system is estimated to reduce carbon dioxide emissions by 2,330.6 Tons (29.4%) and lower lifecycle cost by USD 2.02 million (37.4%) compared with continued diesel operation. According to findings battery-electric conversion can enhance the environmental performance of low-demand regional rail services by reducing operational emissions and offering a sustainable alternative where conventional electrification is impractical.

**Validating a Model of Sustainable Manufacturing in Shared Urban Infrastructures**
**(ID 184)**

Margit Hofer (Zentrum für Soziale Innovation), Robert Mies (Technische Universität Berlin), Elisabeth Unterfrauner (Zentrum für Soziale Innovation), Samire Gurgurovci (Zentrum für Soziale Innovation), Roland Jochem (Technische Universität Berlin)

*Presenting Author:* Robert Mies (Technische Universität Berlin)

**Abstract**. Sustainable manufacturing is widely recognised as essential, yet structural barriers such as fragile supply chains, externalised environmental costs, and the difficulty of implementing circularity remain. Drawing on the principles of the New European Bauhaus, the paper presents the LAUDS factory model: a shared urban manufacturing infrastructure designed to embed sustainability in everyday operations. On the basis of expert interviews and a multi-actor focus group, the model is extended beyond its core dimensions of local, accessible, urban, digital, and sustainable. The empirical process identified five further enabling conditions: governance and participation, collaboration, inclusivity, resilience and continuity, and education and capacity building. Insights are grounded in LAUDS factory infrastructures in three European cities supporting subprojects in circular resource use, energy monitoring, and urban food production. The study finds the original dimensions necessary but not sufficient, and shows how production engineering, governance innovation, and urban integration jointly bridge sustainability awareness and systematic implementation.

| Wednesday, September 23rd, 13:00 - 15:00 | | | |
|---|---|---|---|
| **Decision Support Systems for Circular Economy** | **Sustainable Product Design I** | **Additive Manufacturing** | **Sustainable Supply Chain** |
| King's Court I | King's Court II | Queen's Court I | Queen's Court II |
| Absolute Circularity: A Resource-Based Extension of Absolute Sustainability for Product and Manufacturing Systems (ID 106) | A Systematic Literature Review on the Formalization of Circular Economy Principles in Digital Product Development (ID 73) | Towards Sustainable Metal Additive Manufacturing Using a Low-Cost MAG-Based WAAM System (ID 81) | Efficiency, Resilience, and Resource Constraints: Task-Level Prioritization in Developing Economy Supply Chains (ID 219) |
| Quantifying Circular Economy Performance to Support Evidence-Based Decision-Making in Manufacturing Companies (ID 95) | Beyond Direct Impacts: Identifying Time-Delayed Sustainability Impacts and Systemic Problem Shifts in the Early Stage of Product Development (ID 46) | A Quantitative Sustainability Assessment of Laser Powder Bed Fusion and Additive Friction Stir Deposition (ID 98) | Evaluating Physical Internet–Enabled Shipment Consolidation for Sustainable Supply Chain Operations (ID 37) |
| Towards an Automated Decision Support Method for Circular Business Model Pattern Selection for Manufacturing Companies (ID 79) | Data-Efficient Characterization of IPMSMs using Grey-Box Models for Sustainable Product Development (ID 66) | Performance and Sustainability Evaluation of 3D Printed Minimal Shell Structures Reinforced with Resin and Biofillers (ID 54) | Balancing Sustainability and Resilience in Cereal Supply Chains through Simulation Based Decision Support (ID 38) |
| Towards a Shared Terminology for Product-related Longevity in Circular Apparel Manufacturing in the Context of Emerging Eco-design Regulation: A Structured Literature Based Conceptual Longevity Scheme (ID 183) | Reconfigurable Product Design Considering Sustainability Impacts (ID 83) | A Data-Driven Maturity Model for Prioritizing Digital Spare Part Attributes in Additive Manufacturing Scale-Up (ID 49) | Assessing Supply Chain Resilience using Material Flow Analysis: A Case Study of an Industrial Heat Exchanger Manufacturer (ID 52) |
| Organizational Planning and Decision-Making Processes for Sustainability Transformation in Manufacturing Companies: A Qualitative Interview Study (ID 19) | Topology Optimization for Circular Structural Design with Embedded Reclaimed Components (ID 132) | Cold Spray additive manufacturing using end of life dust-collector–recovered metal powder for circular manufacturing (ID 116) | Managing resilience in multi-tier sustainable supply chains – the case of batteries (ID 204) |
| | | Recycling SS316L Green Parts in Bound Metal Deposition: Quantifying Ceramic Contamination Effects on Dimensional Accuracy (ID 181) | Effect of Geopolitical Disruptions on Sustainable Supply Chain Performance: Multiple Case Studies from Textile and Apparel Manufacturers in the Global South (ID 141) |

# Decision Support Systems for Circular Economy
# Wednesday, September 23rd, 13:00 - 15:00

## King's Court I

### Absolute Circularity: A Resource-Based Extension of Absolute Sustainability for Product and Manufacturing Systems
**(ID 106)**

Nicolas Scherer (Institute of Product Engineering, Saarland University), Kristian König (Institute of Product Engineering, Saarland University), Michael Vielhaber (Institute of Product Engineering, Saarland University)

*Presenting Author:* Nicolas Scherer (Saarland University)

**Abstract**. Product level circular economy assessments commonly rely on indicators such as recycling rates, recirculation measures or related circularity metrics. These approaches are useful for comparing alternatives or improvement options, but they do not by themselves relate material demand to finite-long-term resource availability. This paper introduces absolute circularity as a resource-oriented extension of absolute sustainability for product and manufacturing systems. Building on a finite resource basis, a selected time horizon and an explicit allocation step, an Absolute Circularity Indicator (ACI) is proposed. In the present formulation, the ACI relates the annualized primary material demand of a product system to an allocated annual material budget and is interpreted as a yearly budget consumption indicator. The approach is illustrated for a simplified e-bike product system. The case shows that mass-dominant materials and budget-dominant materials do not necessarily coincide and that the proposed framework can help identify materials for which circular product design as well as manufacturing and recycling improvements may offer the greatest leverage.

### Quantifying Circular Economy Performance to Support Evidence-Based Decision-Making in Manufacturing Companies
**(ID 95)**

Benjamin Gellert (Fraunhofer Institute for Production Systems and Design Technology IPK), Theresa Madreiter (Fraunhofer Austria Research GmbH), Henry Nicolai Buxmann (Fraunhofer Institute for Production Systems and Design Technology IPK), Holger Kohl (Technische Universität Berlin)

*Presenting Author:* Benjamin Gellert (Fraunhofer IPK)

**Abstract**. Manufacturing companies aiming to transform their business models towards circular economy (CE) face multiple challenges, beginning with the measurement of their current circular performance. Without a structured assessment, the identification of circular opportunities, improvement measures or monitoring progress over time remains difficult. This paper addresses this challenge by presenting a systematic approach of CE indicators tailored to the needs of manufacturing companies. The resulting indicator set forms the empirical foundation for a decision support system that derives context-specific circular strategies based on a company's quantified circular performance. The development followed a multi-step process. An initial pool of 158 indicators was compiled by consolidating indicators from sustainability reporting frameworks, international standards and CE maturity models. This pool was reduced to a longlist of 53 indicators by removing duplicates and non-relevant indicators according to predefined relevance criteria. Further consolidation resulted in a shortlist of 32 indicators, which was evaluated with two pilot companies to assess relevance and measurability. The validation led to a final set of 30 qualitative and quantitative indicators grouped into seven thematic clusters. The result is a comprehensive indicator framework that enables evidence-based decision-making and supports the systematic expansion of CE practices in manufacturing companies.

**Towards an Automated Decision Support Method for Circular Business Model Pattern Selection for Manufacturing Companies**
**(ID 79)**

Henry Nicolai Buxmann (Fraunhofer Institute for Production Systems and Design Technology IPK), Lorenz Gudat (Fraunhofer Austria Research GmbH), Benjamin Gellert (Fraunhofer Institute for Production Systems and Design Technology IPK), Holger Kohl (Technische Universität Berlin)

*Presenting Author:* Henry Buxmann (Fraunhofer IPK)

**Abstract**. Transitioning toward a circular economy (CE) is essential for reducing resource consumption, minimizing waste, and fostering sustainable value creation across industries. However, manufacturing companies often face challenges in identifying and implementing the most suitable circular business model (CBM) patterns due to limited analytical and strategic capacities. This paper presents foundational parts of a structured method for developing an automated decision support system (DSS) that guides manufacturing companies in selecting CBM patterns aligned with their operational context and performance priorities. The proposed approach links indicators for circularity to relevant CBM patterns through a systematic mapping process. The methodology further outlines how to determine whether each indicator should exhibit a high or low value for a particular pattern recommendation, as well as how to assign appropriate weights to individual indicators. These relationships form the foundation for constructing mathematical approaches that capture interdependencies between CE indicators and CBM patterns. By formalizing this logic, the study highlights the importance of data-driven reasoning in circular business model innovation and strategic decision-making in manufacturing companies.

**Towards a Shared Terminology for Product-related Longevity in Circular Apparel Manufacturing in the Context of Emerging Eco-design Regulation: A Structured Literature Based Conceptual Longevity Scheme**
**(ID 183)**

Simone Syhre (University of Applied Science Berlin), Juliane Alberts (Hohenstein Innovations gGmbH), Kim Hecht (Hohenstein Innovations gGmbH), Julia Schwarzkopf (University of Applied Science Berlin), Elisabeth Eppinger (University of Applied Science Berlin)

*Presenting Author:* Simone Verena Syhre (Hochschule für Technik und Wirtschaft Berlin)

**Abstract**. Advancing circular manufacturing in the apparel sector requires a shared understanding of sustainability targets and terminology. Current debates on durability, repairability, recyclability, aesthetical and emotional longevity comprise inconsistent terminology, limited comparability of approaches, and hinder the development of coherent industry practices. Without consistent definitions, the translation of regulatory requirements such as eco-design requirements into products remains fragmented. Based on a systematic literature review and situated in the context of the emerging Eco-design for Sustainable Products Regulation (ESPR), this paper presents a conceptual Product Longevity Scheme that structures longevity as a multidimensional construct. It integrates durability, functionality, aesthetics, repairability, increased use, transformability and recyclability, leading to performance, design and information requirements, framed by emotional longevity. This contribution clarifies key concepts, delimits their scope, and systematizes their interrelations without imposing hierarchical prioritization. The scheme forms a foundation for operationalizing measurable criteria, design criteria and test concepts, enabling environmental benefits and circular design strategies within a sustainable manufacturing context.

**Organizational Planning and Decision-Making Processes for Sustainability Transformation in Manufacturing Companies: A Qualitative Interview Study**
**(ID 19)**

Niklas Bode (Institute for Production Management, Technology and Machine Tools (PTW), Technical University of Darmstadt), Oskay Ozen (Institute for Production Management, Technology and Machine Tools (PTW), Technical University of Darmstadt), Laura Belzner (Institute for Production Management, Technology and Machine Tools (PTW), Technical University of Darmstadt), Matthias Weigold (Institute for Production Management, Technology and Machine Tools (PTW), Technical University of Darmstadt)

*Presenting Author:* Niklas Bode (TU Darmstadt PTW)

**Abstract**. The manufacturing industry faces pressure to reduce greenhouse gas emissions, requiring long-term transformation strategies and corresponding investment decisions. Prior research has identified influences, such as organizational structure, playing a crucial role in the adoption of sustainability measures. However, a lack of comprehensive models of organizational planning and decision-making processes for sustainability transformation, as well as the under representation of application-oriented decision-support systems, is apparent. To address these gaps, 18 qualitative interviews with industrial representatives were carried out and subjected to a qualitative content analysis. The interviews reveal multi-phase and iterative organizational planning and decision-making processes, shaped by formal phases, non-standardized analytical methods, and individual agency of actors. Phases as goal formulation, measure development and evaluation could benefit from the integration of decision-support systems, if personal influencing factors are attenuated by in-depth competence development. Implications for the integration of decision-support systems were derived by providing an empirically grounded cross-hierarchical model of organizational planning and decision-making processes.

# Sustainable Product Design I
# Wednesday, September 23rd, 13:00 - 15:00

## King's Court II

### A Systematic Literature Review on the Formalization of Circular Economy Principles in Digital Product Development
**(ID 73)**

Katharina Rohde (Paderborn University, Data Management in Mechanical Engineering), Finn Budde (Paderborn University, Data Management in Mechanical Engineering), Luisa Krogbäumker (Paderborn University, Sustainable Industrialization and Resilient Infrastructure), Manuel Ott (Paderborn University, Data Management in Mechanical Engineering), Iryna Mozgova (Paderborn University, Data Management in Mechanical Engineering)

*Presenting Author:* Katharina Rohde (University of Paderborn)

**Abstract**. Integrating circular economy (CE) principles into digital product development (DPD) is essential to enable sustainable manufacturing. Numerous design guidelines – covering disassembly, reuse, recycling, and maintenance – exist, yet most remain qualitative and are rarely implemented in development environments. This paper presents a systematic literature review that analyzes approaches to formalize CE design knowledge for digital and semi-automated applications. Over 70 peer-reviewed records were initially identified across Scopus, Web of Science, and IEEE Xplore using PRISMA methods, of which approximately 18% met the eligibility criteria for inclusion. The findings reveal isolated work in eco-design and ontology-based knowledge engineering, but no generic framework addressing the integration of multiple CE principles in CAD or PLM systems. Only a few publications translate design guidelines into machine-interpretable formats such as ontologies, rule languages, or STEP / BoM data models. The results indicate a clear separation between sustainability research and digital engineering practice. Bridging these domains through formalized CE rules and interoperable data models will be key to achieving circular, physics-based and data-driven design processes. This review provides a structured overview of existing formalization strategies for circular design knowledge and outlines research directions for advancing sustainable manufacturing through DPD.

**Beyond Direct Impacts: Identifying Time-Delayed Sustainability Impacts and Systemic Problem Shifts in the Early Stage of Product Development**
**(ID 46)**

Wilke Willems (Helmut Schmidt University), Fabian Rusch (Helmut Schmidt University), Frank Mantwill (Helmut Schmidt University)

*Presenting Author:* Wilke Willems (Helmut Schmidt Universität)

**Abstract**. Sustainability assessments are a central instrument in product development, yet they predominantly focus on direct environmental impacts along the product life cycle. Indirect sustainability effects, such as those arising from behavioural adaptations, market responses or systemic dynamics, are increasingly discussed in the literature but remain insufficiently addressed, particularly in early development phases and when they cannot be readily quantified. This paper examines how indirect sustainability impacts in early stages of product development can be systematically structured and comparatively assessed. A mechanism-based approach is developed that abstracts indirect effects into four fundamental mechanisms: compensation, shifting, amplification and possibility space. Based on a structured literature synthesis, a theory-driven qualitative assessment is applied to analyse the potential impacts of these mechanisms across 52 sustainability indicators. The findings indicate consistent structural patterns. Compensation, shifting and amplification are predominantly associated with negative effects, while impacts related to the possibility space are more context-dependent. An initial investigation of a specific product system shows that these patterns remain largely stable, whereas the level of risk varies with the application context. The approach enables a systematic consideration of indirect sustainability impacts in early development phases and supports a broader integration of systemic effects into sustainability assessment.

**Data-Efficient Characterization of IPMSMs using Grey-Box Models for Sustainable Product Development (ID 66)**

Valentin Schemmann (Helmut-Schmidt University), Georg Trautwein (HUCON AG), Behnaz Jafarian (BTU Cottbus-Senftenberg), Armin Fügenschuh (BTU Cottbus-Senftenberg), Frank Mantwill (Helmut-Schmidt University)

*Presenting Author:* Valentin Schemmannn (Helmut-Schmidt University)

**Abstract**. Improving the energy efficiency of technical systems is a key driver of sustainable product development. However, identifying optimal operating strategies typically requires extensive physical testing or simulation-based approaches, which consume significant resources. This paper proposes a model-based approach to reduce experimental effort by utilizing surrogate models derived from limited test bench data. Specifically, a grey-box model was developed for Interior Permanent Magnet Synchronous Machines (IPMSMs) used in automotive applications. By combining physical domain knowledge with data-driven techniques, the resulting Hybrid Neural Network (HNN) predicts total power loss and efficiency maps under varying boundary conditions, such as different temperatures and DC voltage levels, without requiring information about machine parameters or simulation data. The model's analytical part further provides an approximate breakdown into the dominant loss mechanisms. The results demonstrate that this approach enables both reliable interpolation of operating points and prediction of system behaviour across a wide range of conditions, even when design parameters are unknown. Consequently, this research contributes to the resource-efficient development and efficiency improvement of technical systems and proposes that such models may be transferable into the product-use phase, to assist energy-efficient operation and to unlock the potential for efficiency condition monitoring during product use.

**Reconfigurable Product Design Considering Sustainability Impacts (ID 83)**

Thorsten Schmidt (Helmut Schmidt University), Niels Demke (Helmut Schmidt University), Fabian R. Rusch (Helmut Schmidt University), Frank Mantwill (Helmut Schmidt University)

*Presenting Author:* Thorsten Schmidt (Helmut Schmidt University)

**Abstract**. Extending product life cycles can improve resource efficiency and reduce environmental impacts in manufacturing. Circular strategies focus on closing and slowing material loops. However, evolving customer requirements and technological change frequently lead to premature product obsolescence. Product reconfiguration offers a pathway to address this challenge through replacement of functional features, parts, and modules, thereby extending the use phase beyond update and upgrade capabilities. In contrast to repair, reconfiguration requires systematic verification of technical feasibility to ensure that product variants remain safe, compliant, and manufacturable. Implementing reconfiguration strategies requires the application of design principles in development, the organizational integration on an industrial scale, and consistent documentation models. This paper presents a method for evaluating environmental and economic sustainability impacts supporting design and redesign of marketable reconfigurable products. Focusing on variant-rich products, e.g. in the automotive industry, the method systematically analyzes sustainability properties to reduce portfolio complexity, identify reconfiguration-relevant features, and resolve trade-offs between environmental and economic decision conflicts. Two illustrative cases demonstrate the approach for material costs and recyclate ratios itemized from a Configurable Bill of Materials. As a result, reconfiguration contributes to economical evaluation of design principles strengthening the compliance with emerging legislation and deriving documentation models for sustainable manufacturing.

**Topology Optimization for Circular Structural Design with Embedded Reclaimed Components (ID 132)**

O. Nejadseyfi (Computational Design and Mechanics, Precision and Microsystems Engineering Department, Mechanical Engineering Faculty, Delft University of Technology)

*Presenting Author:* O. Nejadseyfi (Delft University of Technology)

**Abstract**. The growing demand for circular production requires structural design methods that support material reuse and component life extension. In many industries, structurally sound components are discarded simply because they do not fit standard design workflows. This work presents a topology optimization framework that allows reclaimed components to be integrated into newly designed structures. Instead of treating reused elements as fixed obstacles, the proposed approach embeds them directly into the optimization process, allowing the surrounding material to adapt around them while considering additive manufacturing constraints. The method is based on density-based topology optimization, where structural performance is optimized while including embedded reclaimed components. As a result, the optimizer can add new material only where needed while making effective use of existing components and minimizing added material. This approach supports lower embodied carbon and reduced raw material use. Numerical examples show that adapting both material layout and component placement improves structural efficiency and the results highlight topology optimization as a useful tool for circular structural design and digitally assisted remanufacturing using reclaimed components.

# Additive Manufacturing
# Wednesday, September 23rd, 13:00 - 15:00

## Queen's Court I

### Towards Sustainable Metal Additive Manufacturing Using a Low-Cost MAG-Based WAAM System (ID 81)

Pamudi Mendis (Department of Mechanical Engineering, University of Moratuwa), P.A.M. Prabasha (Department of Mechanical Engineering, University of Moratuwa), Dehan Dinusara (Department of Mechanical Engineering, University of Moratuwa), Thamasha Samarasinghe (Department of Mechanical Engineering, University of Moratuwa), Eranga De Silva (Department of Mechanical Engineering, University of Moratuwa), Nirosh Jayaweera (Department of Mechanical Engineering, University of Moratuwa)

*Presenting Author:* Pamudi Mendis (University of Moratuwa)

**Abstract**. Sustainable manufacturing focuses on reducing material consumption, energy use, waste generation, and environmental impact throughout the product life cycle while supporting 6R strategies: reducing, reusing, recycling, repairing, refurbishing, and remanufacturing. Metal additive manufacturing supports these principles through near-net-shape fabrication with lower material waste and by enabling repair and refurbishment to extend product lifetime and promote a circular economy. However, most metal additive manufacturing systems rely on expensive proprietary equipment, limiting accessibility in developing countries. Wire Arc Additive Manufacturing (WAAM) offers a practical alternative due to its high deposition rates and efficient material use, although poor surface finish and lower dimensional accuracy remain challenges. WAAM has the potential to be more cost-effective and accessible when implemented using standard welding consumables and equipment. This study presents a low-cost WAAM system integrating a conventional MAG welding unit with a three-axis gantry system. Deposition experiments were conducted to characterise the influence of process parameters on bead geometry and penetration and improve deposition quality. Hence, by eliminating the need for dedicated WAAM platforms and leveraging widely available MAG welding technology, the developed system provides a cost-effective and accessible metal additive manufacturing solution, supporting sustainable metal fabrication practices.

**A Quantitative Sustainability Assessment of Laser Powder Bed Fusion and Additive Friction Stir Deposition (ID 98)**

Nimesh Fernando (Next Generation Additive Manufacturing Research Laboratory (NextGen AMRL), Institute for Sustainable Manufacturing (ISM), University of Kentucky), Syed Ibn Mohsin (Next Generation Additive Manufacturing Research Laboratory (NextGen AMRL), Institute for Sustainable Manufacturing (ISM), University of Kentucky), Fazleena Badurdeen (Next Generation Additive Manufacturing Research Laboratory (NextGen AMRL), Institute for Sustainable Manufacturing (ISM), University of Kentucky), I. S. Jawahir (Next Generation Additive Manufacturing Research Laboratory (NextGen AMRL), Institute for Sustainable Manufacturing (ISM), University of Kentucky)

*Presenting Author:* Nimesh Fernando (University of Kentucky)

**Abstract**. Additive Manufacturing (AM) technologies are progressively transitioning from prototyping to production-scale applications, making the evaluation of their sustainability performance increasingly important. Although the same component can often be manufactured using different AM processes, each with distinct feedstock requirements, operating conditions, and process physics, their sustainability impacts can vary significantly. Therefore, sustainability assessment becomes a crucial decision-making criterion for selecting the most appropriate AM technologies. Among the diverse AM technologies, Additive Friction Stir Deposition (AFSD) is a solid-state process, whereas Laser Powder Bed Fusion (LPBF) is a fusion-based process, resulting in distinct process characteristics and sustainability implications. Therefore, a metrics-based assessment is necessary to systematically evaluate and compare their relative sustainability performance. This paper uses a metrics-based methodology for evaluating the sustainability of AM processes using a Triple Bottom Line (TBL) framework that integrates environmental, economic, and societal dimensions. The framework is demonstrated through a comparative case study involving the fabrication of two identical components using LPBF and AFSD with post-process machining. The results enable a direct comparison of process-specific benefits and trade-offs, highlighting differences in energy consumption, material utilization, cost, and operational impacts. The findings demonstrate that the proposed framework provides a practical and scalable approach for evaluating and comparing sustainability performance across fundamentally different AM technologies.

**Performance and Sustainability Evaluation of 3D Printed Minimal Shell Structures Reinforced with Resin and Biofillers**
**(ID 54)**

Leopoldo De Bernardez (Instituto Tecnológico de Buenos Aires (ITBA)), Cristian Sandre (Instituto Tecnológico de Buenos Aires (ITBA)), Juan Sanguinetti (Instituto Tecnológico de Buenos Aires (ITBA)), Joaquín Infantino (Instituto Tecnológico de Buenos Aires (ITBA)), Sebastian Mur (Instituto Tecnológico de Buenos Aires (ITBA))

*Presenting Author:* Cristian Sandre (Instituto Tecnológico de Buenos Aires (ITBA))

**Abstract**. Fused Deposition Modeling (FDM) enables the fabrication of components with highly complex external geometries, offering a significant advantage over conventional manufacturing processes. However, achieving adequate mechanical performance typically requires high infill densities, which inherently increases printing time, energy consumption, and material usage. This study seeks to expand the conventional boundaries of Design for Additive Manufacturing (DfAM), which traditionally leverages internal architectural complexity, to optimize the balance between structural weight and manufacturing efficiency. With this objective, a hybrid manufacturing strategy is proposed and experimentally evaluated based on the fabrication of minimum layer FDM structures followed by post-process reinforcement using liquid resins, including variants that incorporate lignocellulosic bio-based fillers. Standard ASTM D638 PETG specimens were produced and evaluated under tensile loading to compare fully solid configurations against hollow shells filled with pure polyester resin, as well as resin mixtures containing wood sawdust and short sisal fibers. Mechanical performance was assessed in terms of stiffness, ultimate tensile strength, and failure mechanisms. In parallel, sustainability-oriented indicators were analyzed by correlating these mechanical properties with the estimated printing energy derived from build time. The results demonstrate that resin-reinforced shells can achieve mechanical properties comparable to fully solid FDM parts while significantly reducing both thermoplastic material usage and printing time. Furthermore, the analysis of bio-filler integration demonstrates the feasibility of incorporating renewable materials into hybrid FDM architectures.

**A Data-Driven Maturity Model for Prioritizing Digital Spare Part Attributes in Additive Manufacturing Scale-Up**
**(ID 49)**

Christian Karner (Fraunhofer Austria Research GmbH), Stephan Keckeis (Fraunhofer Austria Research GmbH), Sebastian Schlund (Fraunhofer Austria Research GmbH, Vienna University of Technology, Institute Management Science)

*Presenting Author:* Christian Karner (Fraunhofer Austria Research GmbH)

**Abstract**. Additive manufacturing (AM) has been identified as a promising approach for the flexible and demand-driven supply of spare parts, offering potential reductions in inventory costs and system downtime. Nevertheless, industrial AM adoption for spare parts remains limited, as implementing AM-based solutions requires a level of digital maturity that many components have not yet achieved. In this work, a data-driven maturity model was developed that provides a rational framework for the systematic classification and prioritization of digital spare part (DSP) attributes for AM. The model is based on an analysis of existing maturity models and implementation processes, evaluated for their applicability to DSP. A domain-specific, four-stage maturity model was developed, spanning from master data availability to automated on-demand procurement. Data attributes are defined through a literature review and semi-structured stakeholder interviews with rail and infrastructure sector experts. The data attributes derived from interviews and literature were reconciled and mapped to the maturity model. A scoring approach enables systematic prioritization of data attributes within each stage. The effort required to advance DSPs to the next maturity level is estimated through expert assessments. Future research should address automated data acquisition, dynamic economic parameters, sustainability aspects, and the refinement of attribute weighting.

**Cold Spray additive manufacturing using end of life dust-collector–recovered metal powder for circular manufacturing**
**(ID 116)**

R. Sarvesha (Sustainable Materials Processing and Performance (SMP2) Laboratory, Institute for Sustainable Manufacturing (ISM), University of Kentucky), A.T. Solomon (Sustainable Materials Processing and Performance (SMP2) Laboratory, Institute for Sustainable Manufacturing (ISM), University of Kentucky), M. S. B. Salam (Sustainable Materials Processing and Performance (SMP2) Laboratory, Institute for Sustainable Manufacturing (ISM), University of Kentucky), J. Caudill (Sustainable Materials Processing and Performance (SMP2) Laboratory, Institute for Sustainable Manufacturing (ISM), University of Kentucky), I. S. Jawahir (Sustainable Materials Processing and Performance (SMP2) Laboratory, Institute for Sustainable Manufacturing (ISM), University of Kentucky)

*Presenting Author:* Md Shad Bin Salam (University of Kentucky)

**Abstract**. Cold spray is a solid-state deposition process that enables high-rate coating and repair with minimal thermal degradation, making it an attractive pathway for circular manufacturing. However, the sustainability benefits of CS are often limited by the embodied energy and cost of gas-atomized virgin powders. This study investigates the feasibility of using metal powder recovered from industrial dust-collection systems as a secondary feedstock for cold spray deposition, targeting waste diversion and reduced reliance on virgin powder production. Recovered powders are first subjected to a qualification workflow that includes drying and deagglomeration through a vacuum oven, further sieving/classification to a cold-spray-relevant size fraction. Feedstock quality is assessed through particle size distribution, morphology, and chemistry. Depositions are then produced using a de-Laval nozzle in a parameter window designed to accommodate irregular morphology and higher oxide fraction typical of reclaimed particulates. Further, deposition quality is evaluated via, porosity and interfacial integrity. This work demonstrate that, with minimal preprocessing and parameter optimization, dust-collector–recovered powders can produce dense, adherent deposits, while simultaneously addressing a difficult-to-recycle waste stream and reducing landfill disposal and supporting on-site material recirculation, which is a viable route toward sustainable repair, and circular manufacturing.

**Recycling SS316L Green Parts in Bound Metal Deposition: Quantifying Ceramic Contamination Effects on Dimensional Accuracy**
**(ID 181)**

Manel Chihi (College of Science and Engineering, Hamad Bin Khalifa University), Fawad Ali (College of Science and Engineering, Hamad Bin Khalifa University), Mohammad Albakri (College of Science and Engineering, Hamad Bin Khalifa) University)

*Presenting Author:* Mohammad Albakri (College of Science and Engineering, Hamad Bin Khalifa)

**Abstract**. Bound Metal Deposition (BMD) is a sinter-based metal additive manufacturing process in which metal–binder green parts are produced via material extrusion, followed by debinding and sintering stages to obtain dense metal components. Ceramic interface layers are commonly used during printing to facilitate support removal after sintering. However, this creates a challenge for circular manufacturing, as defective green parts often retain ceramic residues that contaminate recycled feedstock. Such ceramic inclusions can alter shrinkage behavior during sintering, rendering manufacturer-recommended scaling factors unreliable. In this study, the effect of ceramic contamination on debinding and sintering-induced shrinkage is quantified, and contamination-dependent scaling factors are defined for improved dimensional accuracy in BMD. Defective SS316L green parts with controlled $Al_2O_3$ contamination levels (0, 1, and 5 wt.%) were recycled into feedstock. Cylindrical specimens with varying aspect ratios were prepared and sintered under identical conditions to isolate contamination-driven effects. SEM analysis was conducted on recycled feedstock to evaluate powder morphology and ceramic dispersion. Linear shrinkage was then measured to extract revised scaling factors, providing a basis for improving dimensional accuracy when using ceramic-contaminated recycled material.

# Sustainable Supply Chain
# Wednesday, September 23rd, 13:00 - 15:00

## Queen's Court II

### Efficiency, Resilience, and Resource Constraints: Task-Level Prioritization in Developing Economy Supply Chains
**(ID 219)**

W.D.G. Udbhashini (Department of Transport Management and Logistics Engineering, University of Moratuwa), A. Thibbotuwawa (Department of Transport Management and Logistics Engineering, University of Moratuwa), A. Bandara (Department of Operations Management, University of Peradeniya)

*Presenting Author:* W.D.G. Udbhashini (University of Moratuwa)

**Abstract**. Escalating geopolitical volatility has exposed a persistent paradox in global supply networks: firms are expected to remain cost-efficient while also becoming resilient to disruption. Existing research recognizes this tension but gives limited explanation of how it is prioritized across operational tasks, especially in developing economies where resource scarcity, buyer power and institutional volatility constrain managerial choice. This study develops a task-contingent perspective by combining a systematic literature review and bibliometric mapping with semi-structured interviews in the Sri Lankan apparel industry. The review identifies fragmented efficiency, risk and resilience streams, while the interviews show that trade-offs are concentrated in sourcing and inventory, where lean governance limits redundancy and diversification. The findings further clarify how these prioritization decisions influence sustainable manufacturing outcomes, excessive efficiency can create fragile systems that require emergency responses, while excessive redundancy can increase cost, waste and obsolescence. Firms therefore do not achieve a stable firm-level balance; they insert selective resilience practices into efficiency-dominant systems according to task criticality, disruption exposure, sustainability impact and commercial feasibility. The paper contributes to sustainable manufacturing and supply chain resilience research by explaining the boundary conditions under which lean-resilience integration becomes constrained rather than universally attainable.

### Evaluating Physical Internet–Enabled Shipment Consolidation for Sustainable Supply Chain Operations
**(ID 37)**

Ferhat Karayazı (Istanbul Technical University), Fuat Kosanoglu (Istanbul Technical University), Fazleena Badurdeen (University of Kentucky)

*Presenting Author:* Ferhat Karayazı (Istanbul Technical University)

**Abstract**. The rapid growth of e-commerce creates challenges for resource efficiency, cost-effective delivery operations, and environmental sustainability across the supply chain. Addressing these challenges requires integrated and scalable logistics solutions that enhance delivery performance while supporting sustainability goals. This study introduces a framework that integrates the shipment consolidation (SCL) strategies within the Physical Internet (PI) concept to address these challenges and transition towards more sustainable supply chains. However, current literature lacks comprehensive operational, social, and environmental evaluations for PI-based SCL. To bridge this gap, this research develops an empirical assessment framework. In the proposed framework, network operations are coordinated through integrated planning and consolidation mechanisms that improve the use of transport assets and logistics infrastructure. Decentralized decision making among the autonomous logistics actors and infrastructure is captured through an Agent-based simulation model. The study evaluates how PI–enabled coordination influences operational performance and sustainability outcomes, generating insights into trade-offs among efficiency, social and environmental impacts, and system robustness for transitioning toward more sustainable supply chain operations. The simulation results demonstrate that the PI concept increases average vehicle fill rates from 76.5% to 95.8%. Simultaneously, this coordination mitigates traditional network inefficiencies, reducing average per-order emissions to 0.687 kg and yielding a 29% reduction in operational costs.

**Balancing Sustainability and Resilience in Cereal Supply Chains through Simulation Based Decision Support (ID 38)**

Hiran Prathapage (Berlin School of Economics and Law), Dmitry Ivanov (Berlin School of Economics and Law)

*Presenting Author:* Hiran Prathapage (Berlin School of Economics and Law)

**Abstract**. The relationship between sustainability and resilience in supply chain systems is often characterized by inherent tradeoffs, which may lead to conflicting operational decisions and suboptimal performance outcomes. This study integrates a discrete event simulation approach with a real-world cereal supply chain case to examine how network dynamics respond to disruption scenarios while simultaneously considering sustainability and resilience objectives. AnyLogistix software is used to develop simulation scenarios that capture supply chain nodes, links, and key operational variables. Cereal supply chain networks in Mediterranean regions play a critical economic role, yet they are increasingly exposed to climatic, geopolitical, and logistical disruptions while facing growing pressure to achieve sustainability targets. Motivated by these challenges, the research develops a multi criteria decision making framework to support proactive and rapid managerial responses under uncertainty. The framework utilizes performance indicator data generated by the simulations under different conditions to evaluate alternative sourcing strategies. The findings indicate that sourcing from geographically proximate suppliers tends to enhance sustainability performance but limits resilience due to capacity constraints and regional instability. Conversely, suppliers with longer lead times appear to strengthen network resilience through more consistent supply, while adversely affecting sustainability outcomes.

**Assessing Supply Chain Resilience using Material Flow Analysis: A Case Study of an Industrial Heat Exchanger Manufacturer**
**(ID 52)**

Paulina Magdalena Sekuła (Technical University of Denmark, Vestas aircoil A/S), Disna Eheliyagoda (Technical University of Denmark), Wu Chen (University of Southern Denmark), Claus Hessler Ibsen (Vestas aircoil A/S), Devarajan Ramanujan (Technical University of Denmark)

*Presenting Author:* Paulina Magdalena Sekuła (Technical University of Denmark)

**Abstract**. Global material supply chains are increasingly exposed to various risks and disruptions, leading to significant operational challenges and losses in the industrial sector. This article explores the application of Material Flow Analysis (MFA) as a tool for assessing supply chain resilience at the firm level, supporting manufacturers in maintaining operational continuity. MFA quantifies material stock-flow dynamics, providing insights into sustainable resource use. A dynamic MFA model is applied to an industrial heat exchanger manufacturer to assess operational resilience under varying conditions. Several scenarios are constructed, including a business-as-usual case and alternative pathways, to explore how different future conditions may influence supply chain resilience. The results show that integrating MFA into production planning can help firms understand material dependencies and quantify disruption impacts, enabling more robust decision-making under uncertainty. Overall, the study highlights the strong potential of dynamic MFA to support resilient supply chain design and management in manufacturing contexts.

**Managing resilience in multi-tier sustainable supply chains – the case of batteries**
**(ID 204)**

Jannik Neuberger (Supply Chain Management, University of Kassel), Stefan Seuring (Sustainability Management, University of Kassel), Franziska Deicke (Sustainability Management, University of Kassel), Ralf Wagner (Sustainability Management, University of Kassel)

*Presenting Author:* Franziska Deicke (University of Kassel)

**Abstract**. Addressing sustainability issues in battery supply chains (SCs) remains a major challenge for downstream companies, particularly during the mining and refining of raw materials. Multi-tier sustainable supply chain management (MT-SSCM) targets these issues. Meanwhile, supply chain management is facing increasing disruption and shortages. Supply chain resilience (SCR) aims to manage and mitigate such events. This study examines whether MT-SSCM and SCR influence each other and their respective performance metrics, as these two concepts have largely been treated separately in research and practice to date. Drawing on qualitative content analysis of 13 expert interviews, the study reveals that practitioners still view SCR mainly from an engineering perspective rather than as a holistic social-ecological concept. MT-SSCM approaches are widely used across the industry and have been shown to affect resilience performance as well. Upstream integration of mining and refining has emerged as the practice with the greatest impact on advancing both. As MT-SSCM remains dominated by sustainability risk assessments, it should be embedded within an overarching SCR strategy rather than being pursued in parallel. The study advances theory by demonstrating that (MT)SSCM must be considered an integral component of a comprehensive SCR approach, based on social-ecological principles and supported by practices such as upstream integration.

**Effect of Geopolitical Disruptions on Sustainable Supply Chain Performance: Multiple Case Studies from Textile and Apparel Manufacturers in the Global South**
**(ID 141)**

BAJK Rathnayaka (University of Moratuwa), JI Sudusinghe (University of Moratuwa), MMAM Maheepala (University of Moratuwa)

*Presenting Author:* BAJK Rathnayaka (University of Moratuwa)

**Abstract**. The Textile and Apparel industry (T&A) is one of the most globally integrated manufacturing sectors and is highly vulnerable to geopolitical disruptions. Its effects are evident beyond its system's boundaries, yet they are rarely understood. This is especially the case with the Global South of T&A supply chains, where it mainly affects sustainability performance. Hence, this study aims to examine the impact of geopolitical disruptions on the sustainability performance of T&A manufacturers in Sri Lanka and identify potential resilience strategies to address them. A multiple-case study approach was adopted, including six global T&A manufacturers operating in Sri Lanka. Data collected by interviewing senior management were content analyzed, and findings were conceptualized. This study identified three main types of geopolitical disruptions that strongly affect the sustainability performance of supply chains: economy-related, political and social-related, and pandemic-related. The findings indicate that manufacturers adopt proactive strategies for economic-related disruptions affecting profitability and competitiveness, while social and environmental issues are addressed more reactively in the long run. Resilience strategies such as supply chain redesign, demand and supply management were identified. A framework is proposed to assess disruption impacts across supply chain stages, guiding practitioners in prioritizing appropriate phases when implementing resilience strategies.

| Wednesday, September 23rd, 15:15 - 17:15 | | | |
|---|---|---|---|
| **Sustainability Assessment** | **Sustainable Product Design II** | **Sustainability Assessment of Metal Additive Manufacturing** | **Optimization for Sustainability** |
| King's Court I | King's Court II | Queen's Court I | Queen's Court II |
| A Systemic Methodology to Assess Manufacturing Process Sustainability using Techno-Decisional Value Streams (ID 62) | Color Design of Offshore Wind Turbines: A Simulation-Based Analysis for Visual Evaluation (ID 12) | Geometry-Based Predictive Modelling of Energy and Resource Demands in Sustainable Metal Additive Manufacturing (ID 124) | Beyond Cost and Emissions: Integrating Social Objectives into Multi-Objective Energy System Models (ID 147) |
| Integration of Environmental and Economic Performance under Uncertainty: A Scenario-Based Evaluation Methodology for Early-Stage Manufacturing Decisions (ID 189) | A novel framework for cricket helmet design and selection (ID 9) | Development of a Structured Framework for Wire Arc Additive Manufacturing Sustainability Assessment (ID 188) | A Comparative Evaluation of Centralized and Decentralized Multi-Agent Reinforcement Learning for Industrial Energy Management (ID 56) |
| Additive manufacturing versus traditional manufacturing: What conditions justify process substitution for sustainable industrial production? (ID 185) | Design of a Roasted Peanut Skin Removal Machine (ID 159) | Comparing the Environmental Footprints of Direct Energy Deposition and Powder-Based Additive Manufacturing for Titanium Components (ID 76) | Comparing Sensitivity Analysis Approaches within a Framework for Parameter Prioritization in Factory Operations (ID 74) |
| Comparing the impact of Digital Tools versus Renewable Energy regarding Carbon Emissions Reduction (ID 135) | Design and Development of a Banana Fibre Extraction Machine for Sustainable Manufacturing (ID 144) | Comparative Life Cycle Assessment of SiC/SiC Infiltration and Metal Additive Manufacturing for Gas Turbine Blade Production (ID 203) | A Model for Evaluating Advanced Planning and Scheduling (APS) System Implementation Projects in Manufacturing Organizations (ID 16) |
| Mechanisation for Sustainability Assessment in Agri-Food Production Systems: A Case Study of Cinnamon Industry (ID 162) | Experimental Optimization of Low-Energy Fabricated Recycled Polyethylene–Granite Dust Composite Roofing Tiles (ID 200) | Cradle-to-Cradle Carbon Footprint and Supply-Chain Critical Raw Materials of Wire and Arc Additive Manufacturing Next-Generation Aerospace Alloys: A Landing-Gear Wheel Case Study (ID 40) | A Skill-Based Technician Routing and Scheduling Model for Sustainable Maintenance Interventions in Global Customer Service (ID 143) |
| | Towards Low-Carbon Infusion Bags: Material Substitution Strategies for Sustainable Medical Single-Use Products (ID 15) | | Stage-Resolved Monitoring of Industrial Clinker Stability for Sustainable Cement Manufacturing (ID 112) |

# Sustainability Assessment
# Wednesday, September 23rd, 15:15 - 17:15

## King's Court I

### A Systemic Methodology to Assess Manufacturing Process Sustainability using Techno-Decisional Value Streams
### (ID 62)

Pietro Andrea Miciaccia (Department of Mechanical, Mathematics, and Management (DMMM), Polytechnic University of Bari, SKF Industry Spa), Fazleena Badurdeen (Department of Mechanical Engineering, and Institute for Sustainable Manufacturing, University of Kentucky), Michele Dassisti (Department of Mechanical, Mathematics, and Management (DMMM), Polytechnic University of Bari)

*Presenting Author:* Pietro Andrea Miciaccia (Polytechnic University of Bari)

**Abstract**. Sustainability assessment is widely used in manufacturing for decision-making, yet existing approaches typically address product, process, and system within separate analytical domains, leaving their relationships implicit. In this context, the manufacturing technology is generally treated as a predefined condition rather than as a central structuring element shaping manufacturing decisions and configurations. This paper proposes a process-based approach focusing on techno-decisional value streams for sustainability assessment which places the manufacturing process as the central aspect of analysis. Product specifications are considered as upstream constraints, while system configuration represents the downstream implementation of the selected process. Together, these elements form a closed loop systemically linking the product, process, and system aspects during process sustainability evaluation. Sustainability is evaluated through process-level metrics and consistently interpreted across product and system levels through a propagation mechanism. This enables the comparison of alternative manufacturing processes capable of delivering the same product functional requirements under equivalent conditions. The approach is illustrated through an illustrative industrial case study on the production of a Deep Groove Ball Bearing (DGBB). The results show how sustainability performance emerges from process conditions and how different manufacturing solutions can be evaluated based on the resources required to achieve the same product functionality, supporting structured decision-making in manufacturing.

**Integration of Environmental and Economic Performance under Uncertainty: A Scenario-Based Evaluation Methodology for Early-Stage Manufacturing Decisions**
**(ID 189)**

Lukas Nagel (Institute for Production Management, Technology and Machine Tools (PTW), Technical University of Darmstadt), Bahadir Tasbek (Institute for Production Management, Technology and Machine Tools (PTW), Technical University of Darmstadt), Oskay Ozen (Institute for Production Management, Technology and Machine Tools (PTW), Technical University of Darmstadt), Niklas Bode (Institute for Production Management, Technology and Machine Tools (PTW), Technical University of Darmstadt), Matthias Weigold (Institute for Production Management, Technology and Machine Tools (PTW), Technical University of Darmstadt)

*Presenting Author:* Lukas Nagel (Technical University of Darmstadt)

**Abstract**. Achieving sustainability in manufacturing requires decisions that align environmental objectives with economic realities from the earliest stages of production system development. However, existing approaches that combine environmental and economic indicators often lack systematic consideration of uncertainty, early-stage applicability, and a supply chain perspective. Building on a previous PCF forecasting framework, this paper extends early-stage sustainability assessment by integrating probabilistic uncertainty analysis into environmental-economic evaluations. The approach combines scenario analysis and Monte Carlo simulation to quantify the impact of uncertain parameters such as material choice, emission factors, and cost assumptions on environmental and economic outcomes. An industry-based case study in an injection-moulding supply chain demonstrates how variations in material composition, supplier data, and regional electricity mixes influence PCFs and production costs. Results show that material-specific emissions dominate the PCF variability, while upstream emissions vary due to supplier-specific data and regional energy mixes. By simulating plausible parameter constellations, the methodology supports early identification of environmentally and economically preferable production scenarios. The proposed evaluation methodology provides a transparent basis for early-stage comparison of environmental and economic implications without requiring time- and cost-intensive model building.

**Additive manufacturing versus traditional manufacturing: What conditions justify process substitution for sustainable industrial production?**
**(ID 185)**

Gibson P. Chirinda (National University of Science and Technology), Rumbidzai Muvunzi (University of the Witwatersrand)

*Presenting Author:* Not yet updated

**Abstract**. The United Nations (UN) Sustainable Development Goals, particularly Goal 9 (Industry, Innovation and Infrastructure) and Goal 12 (Responsible Consumption and Production), call for resource-efficient manufacturing practices that ensure long-term sustainability. One strategic decision involves selecting the best manufacturing route for a component: additive manufacturing or traditional manufacturing. Both approaches present distinct trade-offs depending on part size, geometric complexity, initial investment and equipment maintenance, production time, production volume, and material usage. When engineers are faced with choosing between additive and traditional manufacturing, under what conditions can additive manufacturing or traditional manufacturing be justified as the preferred process to achieve sustainable industrial production? This study presents a systematic review of the conditions under which additive manufacturing or traditional manufacturing can be the suitable process for industrial production. Following PRISMA-based methodology, 27 peer-reviewed articles from 2021 to 2026 satisfied the inclusion criteria after screening. The findings indicate that despite the expanding industrial adoption of AM technologies and the advancement of TM processes, the consolidation of the diverse parameters required to guide systematic process selection is still lacking as most of the existing studies that were reviewed evaluate technical or economic factors in isolation, without integrating them into a unified decision framework. This variability shows the need for a structured techno-economic based decision-support framework capable of evaluating manufacturing alternatives within modern industrial systems.

**Comparing the impact of Digital Tools versus Renewable Energy regarding Carbon Emissions Reduction**
**(ID 135)**

Georgios Gkoumas (Laboratory for Manufacturing Systems & Automation (LMS), Department of Mechanical Engineering & Aeronautics, University of Patras), Vasiliki C. Panagiotopoulou (Laboratory for Manufacturing Systems & Automation (LMS), Department of Mechanical Engineering & Aeronautics, University of Patras), Panagiotis Stavropoulos (Laboratory for Manufacturing Systems & Automation (LMS), Department of Mechanical Engineering & Aeronautics, University of Patras)

*Presenting Author:* Panagiotis Stavropoulos (Laboratory for Manufacturing Systems and Automation)

**Abstract**. The global temperature rise emphasizes the urgent need to reduce carbon emissions, a primary driver of climate change, to meet international climate goals. Achieving the EU's target of reducing greenhouse gas emissions by 55% by 2030, as outlined in the Green Deal, requires significant focus on adopting renewable energy and enhancing energy efficiency in the most carbon-intensive sectors, which are heavily reliant on fossil fuels. Previous studies have explored the impact of digital tools and energy efficiency methods on reducing industrial emissions. This study focuses on integrating renewable energy sources and compares their effectiveness with digitalization strategies for reducing carbon emissions. It applies a comprehensive framework to evaluate the economic feasibility of these measures, ensuring their financial viability alongside environmental benefits. The research also examines the role of energy storage systems in developing a hybrid energy model that reduces fossil fuel dependency and enhances energy resilience. A secondary steelmaking industry serves as a case study to assess the practical differences between the two solutions for emission reduction.

**Mechanisation for Sustainability Assessment in Agri-Food Production Systems: A Case Study of Cinnamon Industry**
**(ID 162)**

A.A. Darshani (University of Moratuwa), H.N.W. Gunasekara (University of Moratuwa), A.D.U.S. Amarasinghe (University of Moratuwa), J.R. Gamage (University of Moratuwa)

*Presenting Author:* A.A. Darshani (University of Moratuwa)

**Abstract**. Mechanisation is increasingly promoted to improve efficiency and address labour shortages in agri-food production systems; however, its sustainability implications are not uniformly beneficial and therefore require structured evaluation. This study develops and applies a Sustainability Assessment of Food and Agriculture Systems (SAFA) informed sustainability assessment to compare traditionally peeled cinnamon and machine-peeled cinnamon in Sri Lanka. A literature-based indicator selection process was used to define 13 indicators across good governance, environmental integrity, economic resilience, and social well-being. Because industry scale mechanised cinnamon processing is not yet widely adopted, a structured expert-perception questionnaire was administered to 15 cinnamon-sector stakeholders, and paired manual–mechanised ratings were analysed using Wilcoxon signed-rank tests. Mechanised processing was seen to enhance Good Manufacturing Practice (GMP) compliance, production capacity, production rate, price competitiveness, less reliance on skilled labour, food safety, worker safety and societal impact. After Holm correction, the strongest statistically robust improvements were GMP compliance and protection from foreign matter contamination. Manual processing retained advantages in low initial investment and perceived environmental simplicity. The proposed approach provides a structured foundation for assessing mechanisation pathways in cinnamon and other spice processing systems with support of shared facilities, financial models, training and policy measures.

# Sustainable Product Design II
# Wednesday, September 23rd, 15:15 - 17:15

## King's Court II

### Color Design of Offshore Wind Turbines: A Simulation-Based Analysis for Visual Evaluation (ID 12)

KORCHY Hanan (Graduate school of Engineering Science, Akita University), MISHIMA Nozomu (Graduate school of Engineering Science, Akita University)

*Presenting Author:* Hanan KORCHY (Akita Univeristy)

**Abstract**. Offshore wind farms (OWFs) contribute to renewable energy development but often generate concerns regarding their visual impact on coastal landscapes. Although turbine coatings are primarily standardized for engineering durability and safety requirements, limited research has quantitatively examined how turbine color influences visual blending and perceived visibility. This study investigates turbine color as a key design parameter influencing the visual impact of offshore wind farms (OWFs). A computational framework was developed to assess the visual blending performance of turbine colors using image-based perceptual metrics. Five colors were applied to a 3D-rendered OWF under identical geometric, environmental, and viewing conditions. The resulting images were analyzed using Python-based image processing techniques. Perceived color contrast between turbines and their background was quantified using the DeltaE (ΔE) metric and visual saliency, and the normalized outputs were combined into a Blend Index representing overall blending effectiveness, with higher values indicating reduced visual prominence. Beyond visual mitigation, the framework supports sustainable design considerations by informing color strategies that improve landscape integration and social acceptance. The methodology enables comparative ranking of turbine colors and facilitates the integration of visual sustainability into early-stage offshore wind planning and manufacturing design.

### A novel framework for cricket helmet design and selection (ID 9)

Anushika Wijerathna (Department of Mechanical Engineering, University of Moratuwa), Inoka Manthilake (Department of Mechanical Engineering, University of Moratuwa), Himan Punchihewa (Department of Mechanical Engineering, University of Moratuwa, himank@uom.lk)

*Presenting Author:* Himan Punchihewa (University of Moratuwa)

**Abstract**. Personal protective equipment (PPE) must ensure performance with respect to both safety and usability. Although cricket helmets are designed primarily for protection against impact, they are frequently associated with fit-related issues and thermal discomfort which can detrimentally affect performance. To address these challenges, a framework named 'FIT', encompassing the attributes pertinent to Fit, Impact attenuation, and Thermal comfort has been developed through a rigorous research process. This study aims to present the proposed framework and its validation from a sustainable design and manufacturing perspective. The research adopted a mixed-methods approach. Initially, a pictorial representation of the FIT framework illustrating the aspects of fit, impact attenuation and thermal comfort was established. Subsequently, a questionnaire survey and semi-structured interviews were conducted with cricketers (n=11), coaches (n=4), and sports goods vendors (n=2). The responses to the Likert-type questions were analysed using frequency distributions. The results show that all three attributes, i.e., FIT, are critical to helmet performance, making their consideration essential for helmet design, selection and use. The validated FIT framework supports user-centred design, manufacturing and use of helmets promoting material efficiency, enhanced product usability, and extended product life. Although the findings are directly relevant to cricket helmets, the framework has broader applicability across different forms of PPE.

## Design of a Roasted Peanut Skin Removal Machine
## (ID 159)

S.A.K.K. Samaraweera (Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, University of Ruhuna), G.I.P. Perera (Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, University of Ruhuna), K.C.M. Dayananda (Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, University of Ruhuna), A.M.W. Menike (Department of Chemical and Process Engineering, Faculty of Engineering, University of Peradeniya), T.K.K.S. Pathmasiri (Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, University of Ruhuna)

*Presenting Author:* Kithsara Samaraweera (University of Ruhuna)

**Abstract**. Peanut butter is widely consumed as a high protein food product, and the quality of the final product is significantly influenced by the presence of brown skin in roasted peanuts. An acceptable amount of residual peanut skin in peanut butter is limited to approximately 2–3%, as higher levels can lead to undesirable bitterness and reduced sensory quality. Furthermore, the presence of the peanut embryo also contributes to undesirable flavor characteristics in peanut butter. In small-scale peanut butter manufacturing processes, the removal of roasted peanut skin is still commonly performed manually by rubbing the peanuts by hands and winnowing, which is labor intensive, time consuming, and unhygienic. Therefore, there is a need for an efficient mechanical solution to improve the peeling process and maintain product quality within acceptable limits. This study focuses on the design and development of a roasted peanut skin removal machine based on a brush assisted peeling mechanism. This approach is sustainable because it improves peanut butter production efficiency and quality in local industries. A key contribution of this study is the development of a mechanical system capable of simultaneously removing the peanut embryo, which helps reduce bitterness and improve the overall sensory quality of peanut butter.

## Design and Development of a Banana Fibre Extraction Machine for Sustainable Manufacturing
## (ID 144)

J.A.G.S. Madhuwanthi (University of Moratuwa), P.B.P. Nuvinda (Sabaragamuwa University of Sri Lanka), P.K.T.M. Dharmapala (University of Moratuwa), H.K.G. Punchihewa (University of Moratuwa), M.M.I.D. Manthilake (University of Moratuwa)

*Presenting Author:* J.A.G.S. Madhuwanthi (University of Moratuwa)

**Abstract**. The banana pseudostem is a major agricultural waste material obtained from Sri Lankan bananas after the harvest of fruits which is normally used as agricultural waste. But the plant is known to have high strength natural fibres which can be used industrially for manufacturing various products. This research paper describes a machine for extracting the fibre from the pseudostem with a squeezing roller system and chain sprocket scraping method. Testing was done on the extracted fibre through tensile testing using INSTRON Series IX. The fibre yielded a maximum load of 5.918 N and elongation of 0.986 mm, performing better than commercial decorticators and near biological fibres. The process described will help convert banana pseudostem waste into useful material within the scope of circular economy in agro-based industries in Sri Lanka.

**Experimental Optimization of Low-Energy Fabricated Recycled Polyethylene–Granite Dust Composite Roofing Tiles**
**(ID 200)**

K. Mayuresan (Department of Civil Engineering, University of Jaffna), H. K. G. Punchihewa (Department of Mechanical Engineering, University of Moratuwa), H. M. C. C. Somarathna (Department of Civil Engineering, Faculty of Engineering, Sri Lanka Institute of Information Technology (SLIIT))

*Presenting Author:* Krishnamoorthy Mayuresan (University of Jaffna)

**Abstract**. This study presents the experimental optimization of sustainable roofing tiles developed using recycled polyethylene, namely low-density polyethylene (LDPE) and high-density polyethylene (HDPE), reinforced with granite quarry dust through a low-energy, additive-free fabrication process. Composite tiles were produced using a hot-press technique with varying filler contents, and their physical and mechanical properties were evaluated in accordance with relevant Sri Lankan Standards (SLS) and ASTM specifications. Results indicate that density increases with filler incorporation, while water absorption remains below 1% for all compositions, demonstrating excellent impermeability. Flexural performance showed significant improvement at moderate filler content, with peak strength observed at 10 wt.% for both polymer systems. HDPE-based composites exhibited superior load-bearing capacity, achieving transverse strength values of approximately 1910 N, significantly exceeding conventional roofing requirements. At higher filler contents, performance declined due to reduced matrix continuity and particle agglomeration. The optimized composites exhibit a favourable strength-to-density ratio, enabling substantial reductions in structural dead load compared to conventional clay and concrete tiles. The findings demonstrate that recycled polyethylene–granite dust composites provide a viable, low-cost, and environmentally sustainable alternative for roofing applications, contributing to waste valorization and reduced energy demand in the construction sector.

**Towards Low-Carbon Infusion Bags: Material Substitution Strategies for Sustainable Medical Single-Use Products**
**(ID 15)**

Diana Völz (Frankfurt University of Applied Sciences), Julia Schneider (Frankfurt University of Applied Sciences), Verena Linhard (Frankfurt University of Applied Sciences), Ilona Brändlin (Frankfurt University of Applied Sciences), Vinzenz Nienhaus (BIOVOX GmbH)

*Presenting Author:* Diana Völz (Frankfurt University of Applied Sciences)

**Abstract**. Due to their large quantity, infusion bags have a considerable impact on resource consumption and CO2 emissions within the healthcare sector. To meet decarbonization targets, sustainable alternatives are required, as conventional infusion bags are made from fossil-based polymers. This project aims to substitute conventional materials with bio-based plastics, in accordance with all relevant safety and approval requirements. Conventional bags were established as target values for material development. Bio-based plastic compounds were selected, including drop-in and novel bio-based plastics. The films produced from these materials were mechanically and biologically evaluated, and the production process was investigated. The findings indicate mechanical properties comparable to those of the reference bags, but further additives are needed for optimization. Biological tests have confirmed that the samples meet the standard's requirement for biocompatibility at the reference level. Drop-in bioplastics have demonstrated a high degree of integration potential within existing production processes. Conversely, the novel bio-based polymers, which exhibit an enhanced ecological balance, present challenges in terms of utilization and manufacturing. The findings of the study suggest that bio-based infusion bags possess considerable sustainability potential.

# Sustainability Assessment of Metal Additive Manufacturing
# Wednesday, September 23rd, 15:15 - 17:15

## Queen's Court I

### Geometry-Based Predictive Modelling of Energy and Resource Demands in Sustainable Metal Additive Manufacturing
### (ID 124)

Joachim Brinkmann (Trier University of Applied Sciences, Environmental Campus Birkenfeld), Jan C. Aurich (RPTU University Kaiserslautern-Landau), Michael Wahl (Trier University of Applied Sciences, Environmental Campus Birkenfeld), Henrik te Heesen (Trier University of Applied Sciences, Environmental Campus Birkenfeld)

*Presenting Author:* Joachim Brinkmann (Trier University of Applied Sciences, Environmental Campus Birkenfeld)

**Abstract**. Metal additive manufacturing (AM) is increasingly recognised as a sustainable technology due to its extended degrees of freedom in the design process, as well as strategies such as on-demand manufacturing. However, the sustainability performance of AM is heavily dependent on the process-specific energy demand and overall resource utilization. Current assessments often rely on average specific energy consumption (SEC) values without accounting for additional resource flows, auxiliary systems, or geometry-dependent effects. This paper presents a geometry-resolved predictive model for energy and resource demand in PBF-LB/M based on empirical machine data and build-file analysis. High-resolution power data of subsystems and subprocesses of the Renishaw AM400 are combined with scan-vector information and build path strategies extracted from build files. Auxiliary resources, including process gases and feedstock materials, are analysed alongside the electricity consumption. Validation against measurements of actual build jobs demonstrates an accuracy of 94.8%.

**Development of a Structured Framework for Wire Arc Additive Manufacturing Sustainability Assessment (ID 188)**

Mahela Prasanna (Institute for Sustainable Manufacturing, University of Kentucky, Department of Mechanical and Aerospace Engineering, University of Kentucky), Joshua Ade-Omowaye (Institute for Sustainable Manufacturing, University of Kentucky, Department of Mechanical and Aerospace Engineering, University of Kentucky), Syed Ibn Mohsin (Institute for Sustainable Manufacturing, University of Kentucky, Department of Mechanical and Aerospace Engineering, University of Kentucky), Joseph Kershaw (Institute for Sustainable Manufacturing, University of Kentucky, Department of Mechanical and Aerospace Engineering, University of Kentucky), James Caudill (Institute for Sustainable Manufacturing, University of Kentucky, Department of Mechanical and Aerospace Engineering, University of Kentucky), Fazleena Badurdeen (Institute for Sustainable Manufacturing, University of Kentucky, Department of Mechanical and Aerospace Engineering, University of Kentucky)

*Presenting Author:* Mahela Prasanna (University of Kentucky)

**Abstract**. Wire Arc Additive Manufacturing (WAAM), a fusion-based additive manufacturing (AM) process, enables the efficient production of large-scale metallic components at high deposition rates and relatively low cost. While prior studies have reported improved material utilization and energy efficiency compared to conventional manufacturing and some AM processes, these advantages are strongly dependent on part geometry, material selection, and process parameters. Existing WAAM sustainability assessments exhibit substantial variability in system boundary definitions, included process stages, and selected evaluation metrics, thereby limiting comparability and interpretability across studies. To address these limitations, this study establishes a WAAM-specific, metrics-based sustainability assessment framework that integrates economic, environmental, and societal dimensions within a structured hierarchical architecture. A systematic synthesis of published WAAM sustainability studies is conducted, and the reported metrics are mapped to key process stages, including pre-processing, deposition, auxiliary operations, and post-processing. The applicability of the proposed framework is demonstrated through a case study involving the fabrication of a guide bearing under varying process conditions. The results demonstrate that the proposed framework enables a comprehensive, consistent, and reproducible assessment of WAAM sustainability performance. By establishing clearly defined system boundaries and incorporating process-specific metrics, the framework improves reliability and comparability across studies and provides a foundation for more standardized WAAM sustainability evaluation.

**Comparing the Environmental Footprints of Direct Energy Deposition and Powder-Based Additive Manufacturing for Titanium Components**
**(ID 76)**

Georgios Karadimas (Sustainable Manufacturing Systems Centre, Faculty of Engineering and Applied Sciences, Cranfield University), Konstantinos Salonitis (Sustainable Manufacturing Systems Centre, Faculty of Engineering and Applied Sciences, Cranfield University, School of Mechanical & Materials Engineering, University College Dublin)

*Presenting Author:* Konstantinos Salonitis (University College Dublin)

**Abstract**. Direct Energy Deposition and Powder-Based additive manufacturing processes are increasingly used to produce titanium components; however, their environmental performance differs significantly due to contrasting feedstock production routes and process characteristics. Understanding these differences can support informed decision-making when selecting additive manufacturing routes based on sustainability criteria. This paper presents a comparative cradle-to-grave life cycle environmental assessment of the Wire Arc Additive Manufacturing (WAAM) process, as an example of the Direct Energy Deposition class, and Laser Powder Bed Fusion (LPBF) as a representative powder-based additive manufacturing process for the production of a Ti-6Al-4V aerospace component. The assessment quantifies energy consumption and carbon dioxide emissions and evaluates environmental impacts using midpoint and endpoint indicators based on the ReCiPe life cycle impact assessment method. Key life cycle stages include raw material production, feedstock preparation, additive manufacturing, and associated process energy requirements. The results indicate that the environmental performance of the assessed routes differs for the selected component, with life cycle impacts primarily influenced by feedstock processing and material utilisation. This comparative life cycle assessment offers a robust basis for selecting titanium additive manufacturing routes according to environmental and production-scale requirements in aerospace applications.

**Comparative Life Cycle Assessment of SiC/SiC Infiltration and Metal Additive Manufacturing for Gas Turbine Blade Production**
**(ID 203)**

Georgios Karadimas (Sustainable Manufacturing Systems Centre, Faculty of Engineering and Applied Sciences, Cranfield University), Yagmur Atescan Yuksek (Sustainable Manufacturing Systems Centre, Faculty of Engineering and Applied Sciences, Cranfield University), Panos Stavropoulos (Lab of Manufacturing Systems & Automation, Department of Mechanical Engineering & Aeronautics, University of Patras), Konstantinos Salonitis (Sustainable Manufacturing Systems Centre, Faculty of Engineering and Applied Sciences, Cranfield University, School of Mechanical & Materials Engineering, University College Dublin)

*Presenting Author:* Konstantinos Salonitis (University College Dublin)

**Abstract**. Gas turbine blades operate under high temperatures and mechanical loads, requiring materials and manufacturing processes that deliver both performance and efficiency. Ceramic matrix composites such as SiC/SiC are increasingly explored for turbine applications due to their high temperature capability and lower cooling requirements compared with conventional nickel-based superalloys. However, their manufacture commonly relies on chemical vapour infiltration, a process involving multiple stages and significant energy demand. In parallel, metal additive manufacturing has become an established route for producing complex turbine components with improved material utilisation and reduced waste. This study compares two manufacturing routes for gas turbine blade production: SiC/SiC composite fabrication using chemical vapour infiltration and metal additive manufacturing using laser powder bed fusion with a conventional nickel-based superalloy. A life cycle assessment was carried out for the manufacturing stage to evaluate cumulative energy demand, carbon footprint, and midpoint environmental impact categories. Process models were developed from literature data to estimate material flows, energy consumption, and associated emissions for each route. The results highlight differences between the two approaches, mainly driven by process complexity, material preparation, and manufacturing efficiency. The study improves understanding of the environmental trade-offs between advanced composite and additive manufacturing routes and supports the development of sustainable aerospace components.

**Cradle-to-Cradle Carbon Footprint and Supply-Chain Critical Raw Materials of Wire and Arc Additive Manufacturing Next-Generation Aerospace Alloys: A Landing-Gear Wheel Case Study**
**(ID 40)**

Dario Basili (Sustainable Manufacturing Systems Centre, Cranfield University), Eloise Eimer (Welding and Additive Manufacturing Centre, Cranfield University), Emanuele Pagone (Sustainable Manufacturing Systems Centre, Cranfield University)

*Presenting Author:* Emanuele Pagone (Cranfield University)

**Abstract**. The continued growth of air travel is intensifying pressure on the aviation sector to reduce environmental impacts while maintaining stringent performance and safety requirements. Concurrently, the transition toward advanced lightweight alloys may be hindered by concerns about supply-chain fragility linked to critical raw materials and concentrated sourcing. In this context, additive manufacturing is appealing for its characteristic resource efficiency and reduced supply chain complexity. This study compares carbon footprint and supply-chain criticality of three promising next-generation alloys suitable for Wire and Arc Additive Manufacturing (WAAM) of aerospace products. Focusing on an aircraft landing-gear wheel, a "cradle-to-cradle" (i.e. including material production, deposition, post-processing, and end-of-life recycling) carbon footprint model is presented for Al-based Scalmalloy®, Ti-5553 and Mg-ZK60, while considering the impact of the alloys' mechanical properties on the mass of the component. In parallel, a composition-weighted supply-chain criticality index is computed by integrating indicators from EU Critical Raw Materials assessments and the U.S. Geological Survey critical minerals framework. Results highlight trade-offs between lifecycle emissions through lightweighting and critical-material supply risks, showing the necessity to evaluate environmental performance and procurement resilience jointly, when selecting additively manufactured alloys for aerospace components.

# Optimization for Sustainability
# Wednesday, September 23rd, 15:15 - 17:15

## Queen's Court II

### Beyond Cost and Emissions: Integrating Social Objectives into Multi-Objective Energy System Models (ID 147)

Cristian Cafarella (University of Bologna, Department of Industrial Engineering), Michele Ronchi (University of Bologna, Department of Industrial Engineering), Riccardo Siena (University of Bologna, Department of Industrial Engineering), Matteo Gabellini (University of Ferrara, Department of Engineering), Mauro Gamberi (University of Bologna, Department of Industrial Engineering)

*Presenting Author:* Cristian Cafarella (University of Bologna)

**Abstract**. The literature highlights the need for energy system models (ESMs) that go beyond traditional cost minimization approaches and explicitly account for the economic, environmental, and social dimensions of sustainability. However, many multi-objective ESMs still focus on economic-environmental trade-offs, while the social dimension is less frequently included as an explicit optimization objective. To address this gap, this paper proposes a multi-objective optimization approach for integrating social objectives into ESMs. Starting from a baseline cost-emissions formulation, the analysis considers three additional social objectives, i.e., social opposition, job creation, and mortality. The proposed approach supports their explicit inclusion as optimization objectives, the use of benchmark single-objective solutions to explore inter-objective relationships, the generation of Pareto-efficient solutions for systematic trade-off assessment, and the identification of compromise solutions. The applicability of the proposed approach is illustrated through a case study of the Italian electricity system for the target year 2040. In the case study, the selected compromise solution entails only a limited cost increase (+3%) relative to the cost-optimal benchmark, while improving greenhouse gas (GHG) emissions (-11%), social opposition (-7%), job creation (+20%), and mortality (-9%).

**A Comparative Evaluation of Centralized and Decentralized Multi-Agent Reinforcement Learning for Industrial Energy Management**
**(ID 56)**

Luca Werthmann (Institute for Factory Automation and Production Systems (FAPS), Friedrich-Alexander-Universität Erlangen-Nürnberg), Shadi Khamseh (Institute for Factory Automation and Production Systems (FAPS), Friedrich-Alexander-Universität Erlangen-Nürnberg), Jan Hinrich Krüger (Institute for Factory Automation and Production Systems (FAPS), Friedrich-Alexander-Universität Erlangen-Nürnberg), Tobias Reichenstein (Institute for Factory Automation and Production Systems (FAPS), Friedrich-Alexander-Universität Erlangen-Nürnberg), Jörg Franke (Institute for Factory Automation and Production Systems (FAPS), Friedrich-Alexander-Universität Erlangen-Nürnberg), Jens Fürst (Institute for Factory Automation and Production Systems (FAPS), Friedrich-Alexander-Universität Erlangen-Nürnberg)

*Presenting Author:* Luca Werthmann (Friedrich-Alexander-Universität Erlangen-Nürnberg)

**Abstract**. Improving energy efficiency, resilience, and sustainability in manufacturing requires flexible and adaptable systems. However, such systems are difficult to realize with centralized control architectures. Multi-Agent Reinforcement Learning (MARL) promises greater adaptability in dynamic manufacturing environments by integrating multiple agents that act independently, creating emergent behavior. Although MARL approaches have already been applied in the context of sustainability in manufacturing, it remains unclear which architectural design and training paradigms are suitable for achieving reliable and efficient performance in energy management. This paper explores and compares two MARL training paradigms, centralized and decentralized training, using the same environment definition and agent configuration. This ensures that any observed performance differences are attributable to the training paradigm itself. Both approaches are evaluated using two Reinforcement Learning algorithms (Proximal Policy Optimization and Advantage Actor-Critic). The results show that decentralized architectures outperform their centralized counterparts for both learning algorithms, offering faster learning and superior scalability. As the present evaluation is limited to simulation, the approach should be implemented in a real-world demonstrator to validate its functionality under the complexity of industrial energy systems, including hardware limitations and communication delays.

**Comparing Sensitivity Analysis Approaches within a Framework for Parameter Prioritization in Factory Operations**
**(ID 74)**

Luca Philipp (Institute of Production Systems and Logistics / Leibniz University Hannover), Sven Fricke (Institute of Production Systems and Logistics / Leibniz University Hannover), Matthias Schmidt (Institute of Production Systems and Logistics / Leibniz University Hannover)

*Presenting Author:* Luca Philipp (Institute of Production Systems and Logistics)

**Abstract**. The operations of factories with lifetimes up to 40 years affect multiple objectives such as productivity, time, cost, and sustainability that are often subject to trade-offs. Improving one key performance indicator (KPI) may unintentionally deteriorate others. For instance, selecting an alternative energy carrier may reduce energy costs while simultaneously increasing global warming potential. To identify improvement potentials systematically and transparently, quantitative interactions between factory objects, their parameters, and resulting KPIs must be made explicit. This paper presents a framework based on a parameterized, generic factory model that generates consistent datasets describing these interactions across selected parameter groups and KPIs. Building on this foundation, sensitivity analysis approaches are applied and compared as prioritization instruments for identifying high-leverage parameters. The methods are assessed under a common model structure, a common active parameter set, a common baseline parameterization, and harmonized parameter bounds, while preserving the method-specific exploration logic. The comparison evaluates their suitability for prioritizing improvement levers in factory operations. The contribution is a framework-based comparison to support the prioritization of improvement levers in factory operations and to navigate trade-offs between economic and environmental objectives in a structured manner.

**A Model for Evaluating Advanced Planning and Scheduling (APS) System Implementation Projects in Manufacturing Organizations**
**(ID 16)**

W.M.K. Wickramasinghe (Department of Mechanical Engineering, University of Moratuwa), L.U. Subasinghe (Department of Mechanical Engineering, University of Moratuwa)

*Presenting Author:* Lihil Subasinghe (University of Moratuwa)

**Abstract**. To pursue a sustainable future, manufacturers increasingly adopt digital solutions to optimize resources and maintain competitiveness. Circular manufacturing requires precise production orchestration to minimize waste, manage constrained resources, and maintain sustainable inventory levels. Advanced Planning and Scheduling (APS) systems are critical enablers, offering specialized technology to digitalize production planning beyond traditional ERP capabilities. However, implementation complexity remains a significant barrier when achieving expected sustainable benefits. This study supports sustainable digital transformation by developing a stagewise evaluation model to assess APS implementation success. By ensuring effective APS rollouts, organizations can better harvest benefits like reduced manufacturing lead times, optimized resource usage, and lower financial burdens from excess inventory. The study identifies critical success factors (CSFs) and Key Performance Indicators (KPIs) via comprehensive literature review and expert surveys. With the utilization of the Dempster-Shafer theory, this study weights and prioritizes these factors across six implementation stages. The resulting model was validated through case studies in the glove, tire, and yarn manufacturing domains. Results indicate that even in "complete" projects, gaps in stagewise success can hinder operational efficiency. This structured framework ensures digital tools effectively support the resource efficiency required for circular manufacturing, bridging the gap between implementation and successful adoption.

**A Skill-Based Technician Routing and Scheduling Model for Sustainable Maintenance Interventions in Global Customer Service**
**(ID 143)**

Matteo Gabellini (Department of Engineering, University of Ferrara), Alberto Regattieri (Department of Industrial Engineering, University of Bologna), Cristian Cafarella (Department of Industrial Engineering, University of Bologna), Michele Ronchi (Department of Industrial Engineering, University of Bologna), Giacomo Petroselli (Department of Industrial Engineering, University of Bologna)

*Presenting Author:* Matteo Gabellini (University of Ferrara)

**Abstract**. The increasing geographical dispersion of industrial assets and the growing pressure toward environmental responsibility are reshaping global customer service maintenance operations. Although technician routing and scheduling problems have been widely studied, existing models predominantly emphasize cost efficiency and service level compliance, often neglecting the explicit trade-off between operational performance and environmental sustainability, particularly in skill-based maintenance settings. This paper proposes a mixed-integer linear programming model for routing and scheduling multi-skilled technicians performing maintenance interventions in global customer service networks. Technician heterogeneity is captured through performance-based multipliers that affect intervention duration, reflecting different competency levels. This structure generates a critical sustainability trade-off: the most skilled technician may complete an intervention faster but be located farther from the site, implying higher travel-related environmental impact, whereas a closer but less skilled technician may increase service time and operational burden. The model jointly optimizes assignment, scheduling, travel, and return-to-base decisions while explicitly integrating environmental impact and operational costs within a unified objective function. Computational experiments show how the proposed approach supports balanced and sustainability-oriented maintenance planning decisions in global service networks.

**Stage-Resolved Monitoring of Industrial Clinker Stability for Sustainable Cement Manufacturing**
**(ID 112)**

V. Mahawaduge (University of Peradeniya), A. Pallegedara (University of Peradeniya)

*Presenting Author:* Virul Mahawaduge (University of Peradeniya)

**Abstract**. Cement manufacturing needs monitoring methods that can use existing plant data without turning limited evidence into unsupported process or energy claims. Within clinker manufacturing, routine alite and free-lime measurements are important control signals; however, they are downstream outcomes of several upstream material and thermal stages. This study analyses a five-year industrial dataset using a stage-resolved diagnostic workflow across raw meal, kiln meal, hot meal, clinker quality, kiln stop records, and a short raw-mill feed-share subset. Alite is retained as the main routine XRD-derived endpoint signal, while free lime is used as a second clinker-stability endpoint related to burnability and incomplete combination. The clinker endpoint dataset contained 10,040 valid records and 1,530 daily monitoring periods. Mean routine XRD alite was 71.1%, the 5th percentile was 62.8%, and 9.0% of clinker observations were below 65% alite. A conservative Bogue-based calcium-silicate screen gave a mean C3S+C2S value of 74.1%, with approximately 99.4% above the 66.7% reference level. Stage-resolved screening showed that hot-meal variables formed the most informative single upstream audit layer for clinker stability. Logged stop/start windows were enriched in low-alite observations, but not interpreted causally. The contribution is a practical audit-layer workflow for statistical process control and escalation to deeper process variables, not an energy-saving or kiln-causality model.

| Thursday, September 24th, 09:30 - 12:10 | | | |
|---|---|---|---|
| **Industry Session I** | **Simulation for Circular Manufacturing** | **Digital Product Passports** | **Student Session I** |
| King's Court I | King's Court II | Queen's Court I | Queen's Court II |
| | A Decision Support Framework for Resilient and Circular Component Sourcing in Global Production Networks (ID 133) | Managing Change Toward Smart Circular Economy Through the Implementation of Digital Product Passport (ID 153) | Autonomous Rover Instrumentation Package for Precise Temperature and Gas Monitoring in Compost Piles Using STM32 and MATLAB/Simulink (ID 198) |
| | Rethinking ERP-Systems for Remanufacturing: Findings from a Structured Literature Review (ID 140) | A Tool-Based Semantic Network Approach for Structured Design Rule Management in Circular Product Development (ID 67) | Vision Based Four Axis Orientation System for Automated Spoilage Detection for Coconut Industry (ID 179) |
| | State-Space Optimisation of Circular Logistics (ID 71) | Smart Circular Economy Framework within the Digital Product Passport: A Digital Enabler Perspective (ID 152) | Vision guided Robotic Battery Sorting (ID 223) |
| | Supporting Sustainable Manufacturing Systems through Simulation-Based Digital Factory Twins (ID 218) | Towards digital and automated dismantling in the automotive industry: An integrated approach to support circular economy (ID 210) | „EcoBatt“: Design and Prototype Development of an Environmentally Friendly Metal–Air Battery (ID 222) |
| | Simulation-based Decision Support for the Design of Circular Production Systems (ID 60) | Making Smart Remanufacturing Work: An Integrated Architecture for Digital Product Passports, IoT, AI, and ERP Systems (ID 39) | Demo Videogame for a Digital Product Pass adoption in a Smart Circular Economy (SCE) context (ID 224) |
| | Markov Chain-Based Economic and Carbon Assessment of Remanufacturing with Multi-Level Product Structures in Data-Scarce Environments (ID 22) | Integration of economic decision models into automated disassembly stations (ID 10) | Development of a Factory Digital Twin for Carbon Footprint Tracking (ID 225) |
| | Simulation-Driven Circularity Assessment of Recycled Paperboard Manufacturing (ID 53) | Closing Transparency Gaps for NdFeB Magnet Circularity – State of the Art and Requirements for an Upcycling Process (ID 44) | Integrating the Product-Process-System Designs Towards the Circular Economy (ID 70) |

# Simulation for Circular Manufacturing
# Thursday, September 24th, 09:30 - 12:10

## King's Court II

### A Decision Support Framework for Resilient and Circular Component Sourcing in Global Production Networks (ID 133)

Frederik Rincke (wbk Institute of Production Science, Karlsruhe Institute of Technology), Finn Bail (wbk Institute of Production Science, Karlsruhe Institute of Technology), Michael Martin (wbk Institute of Production Science, Karlsruhe Institute of Technology), Gisela Lanza (wbk Institute of Production Science, Karlsruhe Institute of Technology)

*Presenting Author:* Frederik Rincke (wbk Institute for Production Science at KIT Karlsruhe Institute of Technology)

**Abstract**. Manufacturing companies increasingly face volatile supply conditions driven by geopolitical tensions, resource scarcity, and market disruptions. Circular strategies such as remanufacturing can reduce material dependency and enhance circularity, but are characterized by substantial uncertainty in core return volume, timing and quality. These uncertainties complicate sourcing and capacity planning, often leading to either core shortages or excess procurement. This paper proposes a decision support framework for integrated component sourcing in remanufacturing systems. The framework jointly considers two key decisions under uncertainty: (i) the ex-ante determination of long-term contract volumes for linear backup sourcing, and (ii) the dynamic adjustment of core acquisition prices to influence return flows. Core returns are modeled as price-dependent stochastic processes, while demand evolves over time with decreasing uncertainty. The framework evaluates sourcing strategies across contracts, remanufacturing, and spot markets under varying disruption and return scenarios. It explicitly captures the interaction between endogenous return control and sourcing flexibility. The framework enables decision support for balancing cost, resilience, and circularity by integrating return control and sourcing flexibility.

### Rethinking ERP-Systems for Remanufacturing: Findings from a Structured Literature Review (ID 140)

Siegfried Eisele (Technical University of Applied Sciences Augsburg), Michael Krupp (Technical University of Applied Sciences Augsburg), Frank Danzinger (Technical University of Applied Sciences Augsburg), Peter Richard (Technical University of Applied Sciences Augsburg)

*Presenting Author:* Siegfried Eisele (Technical University of Applied Sciences Augsburg)

**Abstract**. Remanufacturing is a crucial strategy for manufacturers towards a Circular Economy. However, its high degree of complexity sets remanufacturing clearly apart from traditional manufacturing processes. Existing information systems, especially Enterprise Resource Planning (ERP) systems, play a pivotal role in whether remanufacturing strategies can be effectively and efficiently pursued. The research aims to shed light on which ERP-related functionalities are identified in extant literature to support remanufacturing and what gaps and limitations are encountered. Therefore, a rigorous structured literature review according to the PRISMA Framework was conducted. The analysis reveals that ERP systems in the domain of remanufacturing are especially recognized for their robust planning functionality and the associated data structures. At the same time, many ERP functionalities cannot be applied in the same way as in conventional manufacturing and therefore need to be adapted or are subject to limitations. The findings indicate that challenges commonly discussed in remanufacturing and disassembly literature remain insufficiently addressed from an ERP systems perspective. This suggests that the ERP community should further investigate how known remanufacturing issues can be reflected in the structure of ERP systems.

**State-Space Optimisation of Circular Logistics**
**(ID 71)**

Charles Kolya (Department of Mechanical and Aerospace Engineering, School of Engineering, University of Manchester), Okechukwu Okorie (Department of Mechanical and Aerospace Engineering, School of Engineering, University of Manchester), Paul Mativenga (Department of Mechanical and Aerospace Engineering, School of Engineering, University of Manchester), Maria Sharmina (Tyndall Centre for Climate Change Research, School of Engineering, University of Manchester), Justyna Rybicka (The Manufacturing Technology Centre (MTC))

*Presenting Author:* Charles Kolya (The University of Manchester)

**Abstract**. Circular supply chain implementation remains a challenge for manufacturers, who must manage resource flows beyond their organisational boundaries. Network design models seek to optimise these flows, but the absence of a quantifiable notion of value has led to inconsistent nomenclature. A scoping review of 19 publications informs the development of a unique state-space representation of retained asset value (v), linked to an endogenous and controllable reservoir of market utility (u). We move beyond cost-minimisation and provide a generic value-maximising objective to act as system governor. Our modelling framework distinguishes between meso-level external flows and micro-level internal transformations, utilising integer variables in a 'remanufacturing stoichiometry'. This approach provides a novel contribution by optimising circular feedback loops, where sales and collection regulate market saturation. Future research opportunities are offered through the integration of predictive analytics to obtain network parameters.

**Supporting Sustainable Manufacturing Systems through Simulation-Based Digital Factory Twins**
**(ID 218)**

Fiona Kattenstroth (Fraunhofer IEM), Jan-Philipp Disselkamp (Fraunhofer IEM), Sebastian Hunger (Fraunhofer IEM), Dennis Withot (Fraunhofer IEM), Ralf Schlosser (Jade University of Applied Science), Roman Dumitrescu (University Paderborn – HNI)

*Presenting Author:* Ralf Schlosser (Jade University of Applied Science)

**Abstract**. Improving the sustainability of manufacturing systems requires data-driven decision support that enables companies to optimise resource utilisation, reduce energy consumption and minimise unnecessary material flows. Digital factory twins (DFT) address this by providing a virtual representation of production systems that allows manufacturers to analyse and optimise processes without interfering with production. Combined with discrete-event simulation (DES), digital twins enable evaluation of alternative production scenarios and planning strategies regarding operational performance and sustainability objectives. However, developing simulation models for DFT poses a key challenge: selecting an appropriate level of modelling detail. Highly detailed models require substantial modelling effort and computational resources, limiting their practical usability for planning tasks. Conversely, overly simplified models may overlook relevant system dynamics, potentially leading to inefficient resource utilisation and reduced sustainability benefits. This paper proposes an approach for determining a suitable level of detail for DES-based DFT in production scheduling contexts. Based on an industrial use case combining material flow simulation with Artificial Intelligence (AI) supported scheduling, the approach enables efficient model development while maintaining accuracy for decision support. The method supports evaluating alternative production schedules to identify strategies that reduce energy consumption, material movements and resource waste, contributing to sustainable and resource-efficient manufacturing systems.

**Simulation-based Decision Support for the Design of Circular Production Systems**
**(ID 60)**

Sazvan Saeed (WZL-IQS | RWTH Aachen University), Friederike von Danwitz (WZL | RWTH Aachen University), Nils Klasen (WZL-IQS | RWTH Aachen University), Amon Göppert (WZL-IQS | RWTH Aachen University), Robert H. Schmitt (WZL-IQS | RWTH Aachen University, Fraunhofer Institute for Production Technology IPT)

*Presenting Author:* Sazvan Saeed (WZL-IQS | RWTH Aachen University)

**Abstract**. Circular production systems (CPS) integrate disassembly and reconditioning of end-of-life products into production systems to enable circular value creation. Designing CPS involves a series of decision-making processes such as the implementation of re-x strategies and layout planning, which are complicated by uncertainties. This work presents a model-driven decision support system for the design of CPS using discrete-event simulation that considers uncertainties in product return quality, station availability and task processing times. The system provides both economic and ecological key performance indicators, including throughput, workstation utilization and estimated saved carbon emissions per product. The application to an industrial use case demonstrates the framework's ability to generate insights into CPS performance, enabling users to identify optimization potential across multiple decision-making processes.

**Markov Chain-Based Economic and Carbon Assessment of Remanufacturing with Multi-Level Product Structures in Data-Scarce Environments**
**(ID 22)**

Siegfried Eisele (Technical University of Applied Sciences Augsburg), Jianing Zhang (Technical University of Applied Sciences Augsburg), Peter Richard (Technical University of Applied Sciences Augsburg), Frank Danzinger (Technical University of Applied Sciences Augsburg)

*Presenting Author:* Siegfried Eisele (Technical University of Applied Sciences Augsburg)

**Abstract**. Remanufacturing represents an important setting lever for implementing the Circular Economy (CE). By reprocessing used products, components and materials, remanufacturing can reduce material and energy consumption compared to manufacturing new products, and thus lower environmental impacts while enabling potential cost savings. While literature provides a variety of modeling approaches, recent studies explicitly emphasize the need for simpler, more robust, and explainable models, especially to support early-stage profitability assessment of remanufacturing. The main objective of this study is to respond to the calls in the literature and to address the process of remanufacturing and its challenges within a single, explainable, and robust Markov model for multi-component products, illustrated through a numerical example based on a publicly accessible dataset. The modeling framework allows for the evaluation of both financial and environmental performance, including CO2-related costs. The results indicate that the proposed model is suitable for the early-stage structuring and evaluation of remanufacturing systems in low-data environments and serves as a baseline for comparison with other modeling frameworks.

**Simulation-Driven Circularity Assessment of Recycled Paperboard Manufacturing**
**(ID 53)**

Michail Pitsios (Department of Civil and Mechanical Engineering, Technical University of Denmark), Rami Mansour (Department of Mechanical and Production Engineering, Aarhus University), Devarajan Ramanujan (Department of Civil and Mechanical Engineering, Technical University of Denmark)

*Presenting Author:* Michail Pitsios (Technical University of Denmark)

**Abstract**. Circularity assessments within process industries are typically static and do not consider the effects of variable operating conditions and process interactions. This paper presents a simulation-driven approach for circularity assessment in recycled paperboard manufacturing, aligned with ISO 59020:2024 circularity indicators. An Aspen Plus model of a real-world paper mill is developed that represents coupled mass and energy flows. The model enables comparing the current process with a future scenario involving internal reuse of treated effluent in pulping. Two circularity indicators: 'energy intensity' and 'water intensity' are evaluated under varying process conditions. Results show that increasing water reuse decreases process energy intensity by up to 12% and water intensity by 49%. Findings show these circularity indicators are intrinsically coupled and exhibit temperature-dependent behaviour, highlighting the value of physics-based simulations for parametric circularity assessment in paperboard manufacturing.

# Digital Product Passports
# Thursday, September 24th, 09:30 - 12:10

## Queen's Court I

### Managing Change Toward Smart Circular Economy Through the Implementation of Digital Product Passport (ID 153)

Carlos Eduardo Silveira (São Carlos School of Engineering at the University of São Paulo), Luana Coelho de Morais (São Carlos School of Engineering at the University of São Paulo), Ingrid Marina Pinto Pereira (Federal University of Amazonas), Carolina Prado Fernandes (São Carlos School of Engineering at the University of São Paulo), Anna-Maria Paust (Institute for Machine Tools and Factory Management, Technische Universität Berlin), Mateus Cecílio Gerolamo (São Carlos School of Engineering at the University of São Paulo, Luiz de Queiroz College of Agriculture, University of São Paulo)

*Presenting Author:* Anna-Maria Paust (Technische Universität Berlin)

**Abstract**. The implementation of the Digital Product Passport (DPP) within the Smart Circular Economy (SCE) has predominantly been examined from a technological perspective, leaving its organizational behavior and change management dimensions underexplored. The goal of this paper is to identify change-management elements to support DPP implementation within the SCE. A two-stage research design was adopted. First, systematic literature reviews (SLR) following PRISMA guidelines identified variables across three core dimensions: Organizational Culture, Leadership, and People Development. These findings resulted in a comprehensive set of 35 identified elements across the three dimensions. Second, this set of elements was validated and prioritized using the Fuzzy Delphi Method (FDM) with industry experts. The FDM application validated all 35 identified elements. The subsequent ranking revealed that Organizational Culture is the primary pillar for transition, accounting for 50% of the Top 20 elements. The high consensus on "Innovation and Creativity" and "Systemic Necessity" indicates that cultural alignment is a prerequisite for technical execution. These findings confirm a state of "Strategic Synchrony": culture enables change, leadership behaviors serve as the motor that drives the process, and people development practices determine how it is operationalized. Ultimately, this comprehensive compilation provides a conceptual foundation for empirical validation, highlighting how culture, leadership, and practices jointly shape organizational readiness for SCE ecosystems.

**A Tool-Based Semantic Network Approach for Structured Design Rule Management in Circular Product Development**
**(ID 67)**

Finn Budde (Paderborn University), Jasper Stichternath (Paderborn University), Katharina Rohde (Paderborn University), Manuel Ott (Paderborn University), Iryna Mozgova (Paderborn University)

*Presenting Author:* Finn Budde (Paderborn University)

**Abstract**. The high environmental impact of today's linear economy increases the pressure to move toward circular product development. To implement circularity in engineering workflows, digital tools and infrastructures are needed that reduce information gaps and represent constraints in a machine-readable way. Design rules capture constraints such as material selection and joining decisions and help ensure manufacturability, quality, safety, and sustainability. In practice, however, design rules are often stored as unstructured natural-language content (e.g., manuals, documents, spreadsheets). This leads to duplicated content, inconsistencies, and limited reuse. This paper presents the conception and implementation of a system to capture existing design rules in a structured form, validate and link them logically. A structured entry interface supports consistent rule authoring using controlled vocabularies and persistent identifiers. Consistency and completeness are checked through validation that combines schema-level checks with rule-level constraints. The captured rules are then converted into a graph-based rule network that makes dependencies and potential conflicts visible and supports systematic rule retrieval and change-impact analysis. Finally, the validated rule knowledge is exported in a structured, machine-readable format, providing a foundation for integration into downstream automation environments and design-assistance workflows in circular product development.

**Smart Circular Economy Framework within the Digital Product Passport: A Digital Enabler Perspective (ID 152)**

Anna-Maria Paust (Technische Universität Berlin), Maxim Mintchev (Technische Universität Berlin), Muhammad Saad (Technische Universität Berlin), Luana Coelho de Morais (Universidade de São Paulo), Mateus Gerolamo (Universidade de São Paulo), Holger Kohl (Technische Universität Berlin)

*Presenting Author:* Anna-Maria Paust (Technische Universität Berlin)

**Abstract**. Global supply chains face growing uncertainty regarding the origin of critical raw materials, lifecycle emissions, and end-of-life management, while regulatory initiatives such as the Digital Product Passport (DPP) further raise transparency requirements. This paper conceptualizes the Smart Circular Economy (SCE) as the coupling of circular strategies with digital industrial technologies and positions the DPP as a core infrastructural element within this ecosystem, enabling product traceability, automated data analysis for process and resource efficiency, and extension of product lifespans by means of reuse, repair, remanufacturing, and return systems. While unique identifiers, data carriers, and a robust data infrastructure are mandatory for a DPP adoption, this paper proposes a framework that articulates how advanced digital technologies, such as artificial intelligence, Internet of Things, blockchain, digital twins, and data spaces, can support DPP deployment. Rather than being mandatory, these technologies are presented as enablers to automate data collection and processing, and achieve higher circular value. The objective of the framework is to sensitize enterprises to the strategic role of advanced digital technologies and how their synergy with DPPs can accelerate the transition towards a SCE.

**Towards digital and automated dismantling in the automotive industry: An integrated approach to support circular economy (ID 210)**

Janine Mügge (Fraunhofer Institute for Production Systems and Design Technology IPK), Theresa Riedelsheimer (Fraunhofer Institute for Production Systems and Design Technology IPK), Erik Freydank (Fraunhofer Institute for Production Systems and Design Technology IPK), Kai Lindow (Fraunhofer Institute for Production Systems and Design Technology IPK)

*Presenting Author:* Janine Mügge (Fraunhofer IPK)

**Abstract**. New regulatory requirements such as the proposed European End-of-Life Vehicles Regulation are increasing the pressure on the automotive industry to establish closed-loop material cycles. Additionally, the manual dismantling of end-of-life vehicles is reaching its limits in the face of growing dismantling requirements. To achieve regulatory compliance and address industrial demands, close integration of digitalization and automation is necessary. Automated systems cannot be realized without digitization, while digital solutions only realize their full potential through automation. A key component is the provision of standardized data throughout the product's entire lifecycle. This data enables informed decisions on circular strategies and disassembly depth. In this paper an analysis of regulatory requirements, industrial developments and needs towards digital and automated dismantling is conducted as well as an integrated concept to support end-of-life decision making is discussed. In addition, quality data captured through automated image recognition is integrated into the decision-making processes. Augmented reality technology assists dismantling workers by displaying relevant information directly in their field of view. At the same time, AR glasses are used to capture process data for further training of robotic systems. This demonstrates how digital technologies and automation solutions can work together to make dismantling processes efficient.

**Making Smart Remanufacturing Work: An Integrated Architecture for Digital Product Passports, IoT, AI, and ERP Systems**
**(ID 39)**

Siegfried Eisele (Technical University of Applied Sciences Augsburg), Peter Richard (Technical University of Applied Sciences Augsburg), Frank Danzinger (Technical University of Applied Sciences Augsburg), Michael Krupp (Technical University of Applied Sciences Augsburg)

*Presenting Author:* Frank Danzinger (Technical University of Applied Sciences Augsburg)

**Abstract**. Remanufacturing has the potential to enable multiple product lifecycles. To unlock this potential, Internet of Things (IoT) technology, combined with artificial intelligence (AI)-based forecasting and the concept of the digital product passport (DPP), must be effectively implemented in the remanufacturing process and seamlessly integrated with information systems. While these domains have been examined separately in the remanufacturing context, integrated approaches that explore their interconnections remain rare. This lack of integration hinders practical application in organizational settings. The main objective of this research was to develop an artifact that models the interplay between the remanufacturing process conducted by original equipment manufacturers (OEMs), forecasting in remanufacturing based on IoT and AI, the DPP, and transaction support by information systems, with a particular focus on enterprise resource planning (ERP) systems. This research adopts a design science research approach to develop an integration architecture that aligns the data and IT systems within the defined scope of this research with the remanufacturing process. The designed architecture was evaluated by an initial analytical economic analysis focusing on two capabilities it enables: cost savings from improved planning and reduced inspection costs through the provision of lifecycle information.

**Integration of economic decision models into automated disassembly stations**
**(ID 10)**

Achim Kampker (Chair of Production Engineering of E-Mobility Components, RWTH Aachen University), Henrik Born (Chair of Production Engineering of E-Mobility Components, RWTH Aachen University), Sebastian Hartmann (Chair of Production Engineering of E-Mobility Components, RWTH Aachen University), Tim Franitza (Chair of Production Engineering of E-Mobility Components, RWTH Aachen University), Quoc Cuong Peter Tran (Chair of Production Engineering of E-Mobility Components, RWTH Aachen University)

*Presenting Author:* Tim Franitza (PEM der RWTH Aachen)

**Abstract**. Critical materials are often lost in current end-of-life practice because complex, highly integrated products are shredded, and downstream sorting cannot deliver material streams of sufficient purity. Moreover, typical particle sizes constrain separability. Selective disassembly could enable recovery, but in practice it is rarely undertaken because the economic case is unclear at the station level and technical solutions are missing. This paper proposes an economic decision model that can be embedded in automated, flexible disassembly stations and is based on requirements related to the recycling of electric motors. The model combines information from a digital product passport (e.g., bill of materials and joining technologies) with up-to-date material prices and parameterized cost functions for disassembly and recycling steps. It evaluates the marginal net value of candidate operations and recommends the economically optimal disassembly depth for each product instance. The output can be used to plan the station's process sequence. By aligning disassembly depth with value recovery, the approach aims to improve the cost-efficiency and attractiveness of automated disassembly while increasing the recovery of critical materials that would otherwise be lost in shredding.

**Closing Transparency Gaps for NdFeB Magnet Circularity – State of the Art and Requirements for an Upcycling Process**
**(ID 44)**

Andreas Muth (Fraunhofer Austria Research GmbH, TU Wien, Institute of Management Science), Stephan Keckeis (Fraunhofer Austria Research GmbH), Sebastian Schlund (Fraunhofer Austria Research GmbH, TU Wien, Institute of Management Science)

*Presenting Author:* Stephan Keckeis (Fraunhofer Austria Research GmbH)

**Abstract**. Digital product passports (DPPs) serve as a critical enabler for circular economy practices by delivering comprehensive product data, with enhanced transparency in the end-of-life (EoL) phase proving particularly beneficial for efficient recovery and recycling. The European Union (EU) targets permanent magnets, especially neodymium-iron-boron (NdFeB) magnets, for DPP implementation, as they represent a vital secondary source of elements for applications in the pharmaceutical, chemical, and ammonia industry – as exemplified by the NEO-CYCLE upcycling initiative. This work defines comprehensive data requirements fostering circular economy practices for products containing NdFeB magnets while ensuring regulatory compliance. Three key data sources are integrated: a systematic literature review, an analysis of relevant legal frameworks, and structured stakeholder interviews with NEO-CYCLE partners for data taxonomy development. Results show that relatively little, yet important research exists on data requirements for sustainable EoL NdFeB magnet processing. Although EU legal approaches largely cover product data, transferring it along the supply chain remains necessary. Batch-based digital material passports preserve informational value amid magnet mixing via automated tracking. Challenges include establishing standardized ontologies and data uncertainty from mixing DPP-equipped with non-equipped products. Future research should address these to enable scalable EoL NdFeB magnet processing in line with EU circular economy goals.

# Student Session I
# Thursday, September 24th, 09:30 - 12:10

## Queen's Court II

### Autonomous Rover Instrumentation Package for Precise Temperature and Gas Monitoring in Compost Piles Using STM32 and MATLAB/Simulink
**(ID 198)**

Bhagya Fernando (Open University of Sri Lanka), Shalika Weerasinghe (Open University of Sri Lanka), Mahizhya Eswaran (Open University of Sri Lanka), Dhivyesh Vakeeson (Open University of Sri Lanka), Ruminda Wimalasiri (Open University of Sri Lanka)

*Presenting Author:* Bhagya Fernando (Open University of Sri Lanka)

**Abstract**. Industrial composting releases most of its methane during the first weeks of decomposition, when emission rates respond sharply to oxygen, moisture and temperature. Intervention within this window requires continuous knowledge of pile state, yet monitoring at working facilities remains manual and intermittent, exposing personnel to emissions and internal temperatures above 90 degrees Celsius, while commercial alternatives are fixed installations priced beyond many operators. This paper presents a rover-mounted instrumentation package developed to close that gap under cost and mobility constraints. Three design decisions follow: a 16-channel analog multiplexer that decouples sensor count from microcontroller cost and leaves headroom for sensor upgrades; model-based development in MATLAB/Simulink on an STM32 platform lacking native support, so an interdisciplinary team can modify the acquisition logic; and an interpretable decision tree classifying pile state as Normal, Warning or Critical onboard. Benchmarked against the manual method it replaces, the temperature subsystem agreed within 0.5 degrees Celsius across a working day, with no observed packet loss and hazard states signalled as expected. The development effort each decision cost is reported, and quantitative classifier evaluation and full-cycle field trials are identified as the principal outstanding work.

### Vision Based Four Axis Orientation System for Automated Spoilage Detection for Coconut Industry
**(ID 179)**

Theja Induwara Weerathunge (Department of Manufacturing & Industrial Engineering, University of Peradeniya), Sandaru Nishara Martinus (Department of Manufacturing & Industrial Engineering, University of Peradeniya), Namal Bandaranayake (Department of Engineering Management, University of Peradeniya), Achala Pallegedara (Department of Manufacturing & Industrial Engineering, University of Peradeniya)

*Presenting Author:* Theja Induwara Weerathunge (University of Peradenya)

**Abstract**. The transition to a sustainable energy future demands professionals with practical knowledge and teaching skills in hydrogen. The European project "H2VE – Hydrogen Valley Vocational Excellence Hub" presents a Guide for Trainer Curriculum offering a structured framework for designing and implementing hydrogen education programs. The guide supports trainers and curriculum developers in structuring modules, applying diverse teaching methods, and addressing the needs of varied target groups, including students, workforce participants, and trainers. Digital teaching tools such as virtual labs, simulation-based learning, and interactive e-learning platforms enable flexible delivery formats, support blended and hybrid learning models, and foster digital competencies alongside technical hydrogen skills. Special emphasis is placed on inclusive learning environments that ensure equal access and participation, and on adaptive learning systems that allow learner-centered pathways tailored to different prior knowledge levels and professional backgrounds. By combining didactic principles with regional considerations, the guide serves as an adaptable reference for developing localized hydrogen training initiatives. Disseminated through a dedicated webinar series, it fosters knowledge exchange among stakeholders and promotes an evidence-based approach to hydrogen education. This initiative builds the competencies necessary to advance the hydrogen economy and strengthen capacities across educational and professional contexts.

**Vision guided Robotic Battery Sorting**
**(ID 223)**

Simla Ulufi (ITQ), Prasannakumar Tamilarasan (TU Berlin), Sourav Subhash Gaikwad (TU Berlin), Saurabh Mahadev Gawade (TU Berlin), Pei-Shin Lin (TU Berlin), Gautam Ajay Bafna (TU Berlin), Ketu Dilipbhai Patel (TU Berlin)

*Presenting Author:* Pei-Shin Lin (TU Berlin) & Ketu Dilipbhai Patel (TU Berlin)

**Abstract**. Repurposing individual lithium-ion cells can reduce material waste and improve resource efficiency. However, reliable detection of defective cells remains essential to ensure safety and performance before reassembly. This study presents a vision-guided robotic system for automated cell screening and sorting. A two-stage deep learning-based detection pipeline (YOLO11) first localizes the relevant cell region and then evaluates cell health through im-age-level classification. The localization model achieved a test mAP50 of 99.50%, while the topview health classifier achieved 86.36% accuracy. Compared with defect-level detection, image-level classification was more suitable for small and diffuse defects such as rust. Fiducial marker (ArUco) calibration converted image coordinates into robot coordinates, enabling a collaborative robot to pick and sort cellsinto healthy and unhealthy categories. The system demonstrates the feasibility of combining computer vision and robotic handling as a rapid first-stage screening method for battery remanufacturing and second-life applications.

**„EcoBatt“: Design and Prototype Development of an Environmentally Friendly Metal–Air Battery**
**(ID 222)**

Chaitanya Singh (Technische Universität Berlin), Vojin Pribak (Technische Universität Berlin), Marius Gernhard (Technische Universität Berlin)

*Presenting Author:* Chaitanya Singh (Technische Universität Berlin)

**Abstract**. This student project explores the development of a environmentally friendly battery concept through the research, design, and construction of a metal-air battery prototype. Conventional batteries often contain materials that are not readily degradable and may raise environmental concerns after use. Metal-air batteries offer a promising alternative because of their high theoretical energy density and their potential to use materials with a lower environmental footprint. The project therefore translates sustainability-oriented battery research into a practical product concept. In an interdisciplinary student setting, the work combines material screening, concept development, CAD-based design, and prototype assembly. Suitable candidate materials are identified and evaluated with regard to sustainability-related properties, while the battery architecture is developed with a focus on practical implementation. The resulting prototype demonstrates how sustainability criteria can be incorporated into the early stages of energy-storage product development. By combining sustainable product design with hands-on engineering and manufacturing methods, this project highlights the potential of student-driven innovation in sustainable manufacturing. It also provides a practical starting point for further refinement and evaluation of environmentally conscious battery concepts.

**Demo Videogame for a Digital Product Pass adoption in a Smart Circular Economy (SCE) context (ID 224)**

Anna-Maria Paust (TU Berlin), Faisal Raza Saiyed (TU Berlin), Prateek Vyas (TU Berlin), Ahilya Ashirwad Bondre (TU Berlin), Valentin Eingartner (TU Berlin)

*Presenting Author:* Prateek Vyas (TU Berlin) & Ahilya Ashirwad Bondre (TU Berlin)

**Abstract**. The Ecodesign for Sustainable Products Regulation (ESPR, Regulation (EU) 2024/1781) will make the Digital Product Passport (DPP) a mandatory instrument for product lifecycle transparency across the European Union. Yet industrial uptake remains low, and no interactive tool currently guides manufacturing professionals through the DPP adoption journey. This paper presents a serious game that teaches DPP adoption within a Smart Circular Economy (SCE) framework. Players act as digitalization managers at a fictitious manufacturer and pro-gress through four phases of increasing digital maturity, repeatedly selling motor batches to raise capital and investing that capital in the digital enablers that complete the passport. The game operationalizes the DPP data model, its eight infra-structure modules, and eight digital enablers, and quantifies progress through a transparent scoring model that combines each technology's degree of automation and technology readiness level into a Smart Circular Economy score. Two hidden decision–disruption mechanics reward anticipatory, systems-level thinking. Architecturally, a single per-phase loop is reused across the productive phases, parameterized only by the sales limit, the technology set, and the random event.

**Development of a Factory Digital Twin for Carbon Footprint Tracking (ID 225)**

Vikaas Ramprasath Setty (Technische Universität Berlin)* Daniyal Zafar (Technische Universität Berlin) Samra Adil (Technische Universität Berlin) Martin Ronak Angello Dsouza (Technische Universität Berlin) Nishant Panse (Technische Universität Berlin) Shabdesh Patil (Technische Universität Berlin) Thanapon Janedittakarn (Technische Universität Berlin) Hrishikesh Vishnu Daware (Technische Universität Berlin)

*Presenting Author:* Daniyal Zafar (Technische Universität Berlin) & Vikaas Ramprasath Setty (Technische Universität Berlin)

**Abstract**. Industrial manufacturing remains a major and persistent contributor to global greenhouse gas (GHG) emissions, with the International Energy Agency reporting record-high energy-related and industrial CO2 output in recent years. Traditional carbon accounting in factories relies on periodic audits and manually compiled data, which are too slow and coarse-grained to support real-time operational decisions or meet growing regulatory reporting demands. This paper presents the development of a factory digital twin designed for continuous carbon footprint tracking, integrating real-time production and energy data with internationally recognized accounting frameworks. The system couples the Asset Administration Shell (AAS), the Industry 4.0 standard for interoperable asset data representation, with GHG Protocol Scope 1–3 emissions accounting and ISO 14040/14044-aligned Life Cycle Assessment (LCA) principles to compute and visualize emissions at the process, line, and factory level. Unlike single-asset or single-process digital twin studies common in the literature, the proposed architecture aggregates heterogeneous plant data into a unified, standardized model and presents results through an interactive dashboard, bridging the gap between technical emissions accounting and managerial decision-making. The work demonstrates how digital twin technology, grounded in established sustainability standards, can transform carbon accounting from a retrospective reporting exercise into a real-time, operational management tool for smart manufacturing environments.

**Integrating the Product-Process-System Designs Towards the Circular Economy**
**(ID 70)**

Themiya Kuruppuge (Exeter Digital Enterprise (ExDES) Lab, Department of Engineering, Faculty of Environment, Science and Economics, University of Exeter), Asela Kulatunga (Exeter Digital Enterprise (ExDES) Lab, Department of Engineering, Faculty of Environment, Science and Economics, University of Exeter), Martino Luis (Exeter Digital Enterprise (ExDES) Lab, Department of Engineering, Faculty of Environment, Science and Economics, University of Exeter), Ion Sucala (Exeter Digital Enterprise (ExDES) Lab, Department of Engineering, Faculty of Environment, Science and Economics, University of Exeter)

*Presenting Author:* Not yet updated

**Abstract**. Various tools and frameworks have been developed to promote the circular economy across product design, manufacturing processes, and supply chain systems. Still, significant fragmentation prevents these developments from reaching their full potential. Existing frameworks address these levels in isolation, failing to capture cross-level dependencies. This paper introduces a multi-level integration framework that addresses these gaps by providing interconnected components that illustrate how recovery strategies function across product, process, and system designs and that facilitate information flow across levels and lifecycle stages. The convergence creates an opportunity to view sustainability not as a constraint checked after designs are finalised but as a design goal enhanced alongside functionality, cost, and quality. Additionally, the proposed framework makes downstream recovery implications visible during early conceptual phases, addressing the temporal mismatch between when design decisions are made and when their circularity consequences become apparent. The framework enables practitioners to implement circular economy principles across organisational silos while providing a robust foundation for developing cross-level decision-making support.

| Thursday, September 24th, 13:10 - 15:10 | | | |
|---|---|---|---|
| **Industry Session II** | **Life Cycle Assessment** | **Manufacturing Process I** | **Student Session II** |
| King's Court I | King's Court II | Queen's Court I | Queen's Court II |
| | Industry 4.0 as an Enabler for Process-Level Life Cycle Assessment in Machining (ID 23) | Energy Efficiency and Microstructural Characterization of Dissimilar Ti-6Al-4V and Copper Joints Produced by Cold Gas Tungsten Arc Welding (ID 72) | Mapping & Service Finder for specific technology infrastructure on sustainable manufacturing in urban settings (ID 227) |
| | Advancing Sustainability in Energy-Intensive Industries: Development and Value of Dynamic LCA Modules (ID 136) | High-Precision Brushing as a Sustainable Finishing Strategy for Cold Forming Tool Surfaces (ID 119) | Waste Gas Electrification (ID 229) |
| | Evaluating Tactical Environmental Mitigation Strategies Using Life Cycle Assessment: A Study of the Ceramic Tableware Industry (ID 195) | Interpolation-Free Inverse Identification of Material Behavior from In Situ Velocity Fields During Machining (ID 212) | Design and Development of Natural Fiber based Composites for Food Packaging industry (ID 167) |
| | Life Cycle Assessment of Plastic Waste–Integrated Lemon Peel Activated Carbon Composites for Sustainable Material Production (ID 155) | A Structured Framework for the Sustainable Modernization of Progressive Die Stamping – Research Gap Identification and a Conceptual Model for Process Transformation (ID 122) | Design and development of a combined domestic food waste drying, crushing, and pelletizing machine (ID 213) |
| | Carbon and Energy Implications of Furnace Configuration in Activated Carbon Production from Sugarcane Bagasse: A Life Cycle Perspective (ID 154) | Performance Evaluation of Brazed Carbide Cutting Tools for Cycle Time and Energy Reduction in Machining of Brass Alloys (ID 187) | Design and development of a machine for producing plastic-based bricks from waste PET plastic. (ID 156) |
| | Environmental impact assessment of additive and conventional manufacturing methods for tissue engineering scaffolds (ID 216) | | A Process-Integrated Value Chain Sustainability Framework for Upcycling Polypropylene Feedstocks in Fused Deposition Modeling (ID 220) |

# Life Cycle Assessment
# Thursday, September 24th, 13:10 - 15:10

## King's Court II

### Industry 4.0 as an Enabler for Process-Level Life Cycle Assessment in Machining (ID 23)

Ralf Schlosser (Jade University of Applied Sciences), Moritz Schäfer (Jade University of Applied Sciences), Peter Frank (Georg Agricola University of Applied Sciences)

*Presenting Author:* Moritz Schäfer (Jade University of Applied Sciences)

**Abstract**. The integration of Industry 4.0 (I 4.0) technologies into manufacturing processes is a critical factor for enhancing the precision of Life Cycle Assessments (LCAs). This paper addresses the challenges of accurate data acquisition in the manufacturing sector, specifically focusing on the limitations of traditional manual data collection, which often result in significant gaps, inaccuracies, or prohibitive costs. By leveraging I 4.0 solutions - including smart sensors, Internet of Things (IoT) platforms - this study demonstrates a methodology to capture precise, product- and process-specific data. The results indicate that the implementation of such a digital framework significantly improves data quality and accessibility, thereby enabling more granular and reliable LCA outcomes. Furthermore, the findings suggest that the adoption of these technologies streamlines the Life Cycle Inventory (LCI) phase and enhances the overall environmental sustainability of manufacturing operations.

### Advancing Sustainability in Energy-Intensive Industries: Development and Value of Dynamics LCA Modules (ID 136)

Evangelia Xydea (Laboratory for Manufacturing Systems & Automation (LMS), Department of Mechanical Engineering & Aeronautics, University of Patras), Vasiliki C. Panagiotopoulou (Laboratory for Manufacturing Systems & Automation (LMS), Department of Mechanical Engineering & Aeronautics, University of Patras), Konstantinos Salonitis (UCD School of Mechanical and Materials Engineering), Panagiotis Stavropoulos (Laboratory for Manufacturing Systems & Automation (LMS), Department of Mechanical Engineering & Aeronautics, University of Patras)

*Presenting Author:* Panagiotis Stavropoulos (Laboratory for Manufacturing Systems and Automation)

**Abstract**. Energy-intensive industries are currently experiencing increased pressure to comply with Clean Industrial Deal and EU Green Deal, to significantly reduce their carbon emissions by 2030 and reach carbon-neutrality by 2050. Several tools have been developed and are being deployed towards this direction, with life cycle assessment (LCA) being on the core of these developments. There are several LCA approaches and techniques, often needing long time to provide a result. The aim of this paper is to demonstrate the added value of dynamic LCA modules tailored to energy-intensive industries. In this study, we outline the requirements and specifications, including type of data, software and hardware required. The dynamic LCA case is then applied into a steel industry case, highlighting the implementation route, and describing the inclusion of the dynamic LCA in decision making tools for a greener steel production. Limitations are outlined, with areas for further exploration included.

**Evaluating Tactical Environmental Mitigation Strategies Using Life Cycle Assessment: A Study of the Ceramic Tableware Industry**
**(ID 195)**

Madhurika Geethani (University of Moratuwa), Subodha Dharmapriya (University of Peradeniya), Asela Kulatunga (University Exeter), Nisal Warnakulasooriya (University of Peradeniya)

*Presenting Author:* Madhurika Geethani (University of Moratuwa, Moratuwa)

**Abstract**. Ensuring sustainability has become a critical challenge in the ceramic tableware industry due to the energy and material intensity of its processes. Therefore, adopting a life cycle engineering approach to evaluate the environmental effectiveness of decisions implemented in this sector is essential. This study applies the Life Cycle Assessment (LCA) methodology to evaluate the environmental performance of four tactical decisions, including replacing a portion of imported kaolin with local material, recycling damaged biscuit ware, implementing an alternative process path for whiteware products, and reducing the glost kiln firing cycle. The analyses were conducted in accordance with the methodological guidance outlined in ISO 14040 and ISO 14044, from a cradle-to-gate perspective using one ton of finished product as the functional unit. While all assessed decisions yield positive environmental benefits compared to existing operational conditions, the alternative process path for whiteware demonstrates the best performance. The findings of the study provide actionable insights for decision-making regarding the adoption of more sustainable manufacturing practices.

**Preliminary Assessment of the Environmental Performance of Mixed Plastic Waste–Integrated Lemon Peel–Derived Activated Carbon Composites**
**(ID 155)**

Junaid Saleem (Division of Sustainable Development, College of Science and Engineering, Hamad Bin Khalifa University, Qatar Foundation), Zubair Khalid Baig Moghal (Division of Sustainable Development, College of Science and Engineering, Hamad Bin Khalifa University, Qatar Foundation), Furqan Tahir (Division of Sustainable Development, College of Science and Engineering, Hamad Bin Khalifa University, Qatar Foundation), Gordon McKay (Division of Sustainable Development, College of Science and Engineering, Hamad Bin Khalifa University, Qatar Foundation)

*Presenting Author:* Junaid Saleem (Hamad Bin Khalifa University)

**Abstract**. Integrating biomass residues with plastic waste into hybrid carbon–polymer materials offers a promising pathway toward circular material production; however, the environmental implications of such integrated systems remain insufficiently quantified. This study presents a preliminary, process-resolved life cycle assessment (LCA) of mixed plastic waste–integrated lemon peel (LP)–derived activated carbon (AC) composites using $H_3PO_4$ activation. The system boundary encompasses collection, transport, shredding, drying, pyrolysis under $N_2$ atmosphere, chemical activation and neutralization, solvent-assisted polymer dissolution using xylene, and post-heat treatment for the production of 1 kg of composite. The environmental impacts were quantified as 6.58 kg $CO_2$ eq. for climate change (CC) and 171 MJ for net energy demand (EN). The relatively elevated impacts are primarily attributed to energy-intensive thermal processes and solvent-assisted polymer processing. A comparative assessment of different electricity sources—including natural gas, photovoltaic, and biomass-based systems—revealed that biomass-derived electricity results in the lowest CC and EN, significantly improving overall environmental performance. These findings highlight the critical role of energy source selection and solvent-intensive processing in determining the sustainability of LP–plastic hybrid carbon materials, and provide important insights for the design and scale-up of environmentally optimized composite production systems.

**Carbon and Energy Implications of Furnace Configuration in Activated Carbon Production from Sugarcane Bagasse: A Life Cycle Perspective**
**(ID 154)**

Junaid Saleem (Hamad Bin Khalifa University), Zubair Khalid Baig Moghal (Hamad Bin Khalifa University), Furqan Tahir (Hamad Bin Khalifa University), Gordon McKay (Hamad Bin Khalifa University)

*Presenting Author:* Junaid Saleem (Hamad Bin Khalifa University)

**Abstract**. Process configuration plays a decisive role in determining the environmental performance of activated carbon (AC) production, often outweighing the influence of precursor selection. Among process stages, pyrolysis is particularly energy-intensive; however, the life-cycle implications of furnace configuration remain insufficiently quantified. This study presents a preliminary life cycle assessment (LCA) of AC produced from sugarcane bagasse (SB), explicitly comparing chamber (CF) and tubular furnace (TF) pyrolysis under equivalent operating conditions. Environmental impacts were evaluated in terms of climate change (CC), net energy demand (EN), fossil depletion (FD), and particulate matter formation (PMF), complemented by contribution analysis to identify dominant process stages. The results confirm that pyrolysis is the principal environmental hotspot in both systems. Pyrolysis contributes 82% and 79% of CC and EN in the CF configuration, increasing to 87% and 85%, respectively, in the TF system. Overall, the CF exhibits lower EI, with CC of 5.11 kg $CO_2$ eq. and EN of 115 MJ. In contrast, the TF results in significantly higher burdens, reaching 7.25 kg $CO_2$ eq. and 162 MJ, respectively, primarily due to continuous heating requirements and lower effective material utilization. These findings demonstrate that furnace configuration is a critical determinant of carbon and energy performance in SB–derived AC systems and highlight the importance of integrating process-level design considerations into life-cycle-driven optimization of AC production.

**Environmental impact assessment of additive and conventional manufacturing methods for tissue engineering scaffolds**
**(ID 216)**

Mohit Kumar (Indian Institute of Technology Bombay), Varun Sharma (Indian Institute of Technology Roorkee), Tanmay Tiwari (The University of Akron), Chandra Sekhar Rakurty (The M.K. Morse Company)

*Presenting Author:* Mohit Kumar (Indian Institute of Technology Bombay)

**Abstract**. This study focuses on the inverse identification of an elasto-viscoplastic constitutive model for copper alloys using full-field kinematic measurements obtained from a uniaxial tensile test.<br/>Displacement and strain fields are measured using Digital Image Correlation (DIC) and employed as inputs in an inverse identification framework that combines finite element simulations with an optimization procedure. The identified parameters correspond to a strain-rate- and temperature-dependent constitutive model based on Johnson–Cook formulation.<br/>The comparison between experimental and simulated strain fields demonstrates the robustness of the approach and its ability to capture local deformation mechanisms. This work contributes to improving the calibration of constitutive models under conditions representative of high strain-rate processes such as metal cutting. The proposed framework therefore provides a relevant basis for enhancing the predictive modeling of materials subjected to severe thermomechanical loading.

# Manufacturing Processes I
# Thursday, September 24th, 13:10 - 15:10

## Queen's Court I

### Energy Efficiency and Microstructural Characterization of Dissimilar Ti-6Al-4V and Copper Joints Produced by Cold Gas Tungsten Arc Welding
**(ID 72)**

Mariia Rashkovets (Department of Mechanics, Mathematics and Management, Polytechnic University of Bari), Vito Denora (Department of Mechanics, Mathematics and Management, Polytechnic University of Bari), Nicola Contuzzi (Department of Mechanics, Mathematics and Management, Polytechnic University of Bari), Michele Dassisti (Department of Mechanics, Mathematics and Management, Polytechnic University of Bari), Giuseppe Casalino (Department of Mechanics, Mathematics and Management, Polytechnic University of Bari)

*Presenting Author:* Pietro Andrea Miciaccia (Polytechnic University of Bari)

**Abstract**. The development of sustainable manufacturing requires joining technologies that combine low energy consumption, reduced environmental impact, and high reliability. This study investigates cold gas tungsten arc welding (CGTAW) for joining Ti-6Al-4V and DHP-CW024A alloys. The process employs complete and controlled arc shutdown to limit heat input and suppress excessive intermetallic compound formation without the use of filler material, enabling full-penetration joints. Compared with conventional Pulse-GTAW, CGTAW reduced electrical energy consumption by approximately 45% while decreasing arc operating time. Microstructural analysis revealed that rapid cooling promotes a simple and stable interfacial transition (Cu → α'-Ti → Ti solid solution with a limited amount of $Ti_2Cu$), contributing to improved joint quality. The results demonstrate that CGTAW is a promising approach for the sustainable and energy-efficient welding of dissimilar Cu–Ti alloys.

### High-Precision Brushing as a Sustainable Finishing Strategy for Cold Forming Tool Surfaces
**(ID 119)**

Peter Frank (Technische Hochschule Georg Agricola), Jonas Teichert (Technische Hochschule Georg Agricola), Arne Oleszak (Technische Hochschule Georg Agricola), Ralf Schlosser (Jade Hochschule), Stefan Hoppe (esw GROUP), Matthias Otto (esw GROUP), Sandro Grimm (esw GROUP)

*Presenting Author:* Peter Frank (Technische Hochschule Georg Agricola)

**Abstract**. Cold metal forming is resource-efficient due to its near-net-shape character and high material utilization. Tool surface conditions and finishing operations during manufacturing significantly influence process performance. In industrial practice, manual polishing remains the predominant method, accounting for up to 50% of total tool manufacturing time and involving substantial labor effort and process media consumption. The objective of this study was to evaluate the application potential of high-precision brushing as an automated and dry finishing strategy for cold-forming tools. The focus was on verifying its capability to generate functionally equivalent surface states compared to manual polishing and to assess their tribological behavior using ring compression tests. Pilot studies demonstrate that brushing can produce surface qualities comparable to manually polished tools. Through systematic variation of process and tool parameters, functionally relevant Abbott–Firestone parameters can be adjusted in a controlled and reproducible manner. Building on these findings, forming dies with different HSC milling step-over widths were brush-finished and evaluated using ring compression tests. The results reveal a correlation between surface topography and tribological stability.

**Interpolation-Free Inverse Identification of Material Behavior from In Situ Velocity Fields During Machining (ID 212)**

Tristan Chenevez (LaBoMaP), Jihane Arbi (LaBoMaP), Hélène Elias-Birembaux (LaBoMaP), Frédéric Rossi (LaBoMaP)

*Presenting Author:* Tristan Chenevez (LaBoMaP)

**Abstract**. Predictive machining simulations are used to reduce empirical trial-and-error when selecting cutting conditions, estimating tool loading and assessing thermomechanical fields in the cutting zone. Their reliability depends strongly on constitutive parameters representative of the severe strain-rate and temperature conditions encountered during cutting. This paper presents an interpolation-free inverse identification framework based on in situ DIC-derived velocity fields and a CEL finite element model of orthogonal cutting. The key feature is a DIC-aligned finite element discretization: the local element layout is defined so that the Gauss integration points used for field extraction are located at the DIC measurement positions. The velocity-field discrepancy is then evaluated directly at coincident DIC/Gauss-point locations, without spatial interpolation. The framework is complemented by a numerical sensitivity analysis of the simulated velocity field, providing a preliminary qualitative assessment of parameter identifiability before a complete inverse identification campaign which will be carried out in the near future to achieve a comprehensive quantitative parameter estimation.

**A Structured Framework for the Sustainable Modernization of Progressive Die Stamping – Research Gap Identification and a Conceptual Model for Process Transformation (ID 122)**

Dawid Bogdanowicz (Wroclaw University of Science and Technology), Maria Rosienkiewicz (Wroclaw University of Science and Technology)

*Presenting Author:* Dawid Bogdanowicz (Wroclaw University of Science and Technology)

**Abstract**. Progressive die stamping is a widely used high-volume metal forming process in automotive, electrical, and appliance industries. While highly productive and technologically mature, its optimisation has traditionally focused on throughput, quality, and cost, with limited integration of environmental performance at the process level. Existing sustainable manufacturing research addresses life cycle assessment, energy efficiency, and circular economy strategies, but is predominantly conducted at product or system level. As a result, the relationships between process parameters, equipment condition, resource consumption, and environmental impact remain insufficiently explored in progressive die stamping, particularly in legacy production systems. This paper identifies a research gap in the lack of a structured framework linking operational decision-making with sustainability performance at the process level. To address this gap, a conceptual framework for the sustainable modernisation of progressive die stamping is proposed. The framework integrates process characterisation, sustainability-oriented performance assessment, and improvement actions within a unified decision-support structure. The study provides a foundation for future research aimed at developing and validating process-level sustainability models under industrial conditions.

**Performance Evaluation of Brazed Carbide Cutting Tools for Cycle Time and Energy Reduction in Machining of Brass Alloys**
**(ID 187)**

Mehmet Mert Gümüş (Torun Metal A.Ş.), Evren Toraman (Torun Metal A.S.), Süleyman Çiçek (Torun Metal A.Ş.), Yusuf Kaynak (Marmara University)

*Presenting Author:* Yusuf Kaynak (Marmara University)

**Abstract**. Improving machining efficiency is a key indicator of sustainable manufacturing due to its direct impact on energy consumption and resource utilization. This study presents the design and experimental validation of a complex brazed multi-stage drilling tool developed to reduce cycle time in machining of brass alloys in serial production.

In the conventional process, the component requires three sequential cutting operations using three separate standard tools. Each operation involves cutting time, tool retraction, and tool change, increasing cycle time and thus energy consumption. The cumulative effect results in a high total cycle time per part.

To address this limitation, a custom brazed drilling tool integrating three cutting stages into a single body was designed. The tool enables simultaneous execution of all drilling operations in one pass, eliminating intermediate tool changes. Geometric optimization ensured dimensional accuracy and stable chip evacuation while maintaining cutting performance.

Machining tests were performed to calculate cycle time and energy consumption under flood cooling conditions. Our study demonstarted that approximaetly 40% reduction in total cycle time compared to the conventional method was achieved. Cutting force measurements also confirmed this advantedges.

The findings demonstrate that integrated tool design can significantly improve process sustainability by reducing energy usage while enhancing productivity in serial production.

# Student Session II
# Thursday, September 24th, 13:10 - 15:10

## Queen's Court II

**Mapping & Service Finder for specific technology infrastructure on sustainable manufacturing in urban settings**
**(ID 227)**

Harsith Suresh Kumar (TU Berlin)* Pradosh Kandasamy (TU Berlin) Yash Amit Barhanpurkar (TU Berlin) Robert Mies (TU Berlin) Julien Colomb (TU Berlin)

*Presenting Author:* Harsith Suresh Kumar (TU Berlin) & Yash Amit Barhanpurkar (TU Berlin)

**Abstract**. Not yet updated

**Waste Gas Electrification**
**(ID 229)**

Clemens Biet (TU Berlin) Kiran Dev Thottungal Kuttihari (TU Berlin) Kartiki Anup Gujar (TU Berlin) Vedanti Kiran Walokar (TU Berlin) Chandramouli Mahendra (TU Berlin) Fangyuan Ran (TU Berlin) Valentin Eingartner (TU Berlin)

*Presenting Author:* Kartiki Anup Gujar (TU Berlin)

**Abstract**. Methane emissions have large short-term impact on climate. Landfills and abandoned coal mines emit methane, contributing high CO2 equivalent emissions. Decentralized power plants are used to produce electricity by burning this waste gas. Over years of operation, the methane concentration declines, which leads to the reduction of engine efficiency and eventually forces the plant to shut down. A solution approach is to mix a small amount of hydrogen into the waste gas which improves efficiency and combustion stability. As a means of on-site hydrogen production, the utilization of low cost and high efficiency ZZE electrolyser was investigated. ZZEs can also store energy which allows power plant operation to electricity prices. To evaluate the feasibility of a ZZE supported mine gas power plant, a simulation was conducted. The model included competing versions and operating modes of the power plant. Based on the simulation results, an economic and environmental assessment of the waste gas electrification approach was made. The ZZE is able to extend the operating life of a mine-gas plant while cutting methane emissions and increasing profits.

**Design and Development of Natural Fiber based Composites for Food Packaging industry (ID 167)**

Danish Sathurshihan (Faculty of Engineering, University of Ruhuna)

*Presenting Author:* Danish Sathurshihan (Faculty of Engineering, University of Ruhuna)

**Abstract**. Packaging plays a pivotal role in the food industry, protecting and preserving the quality of goods for storage and transportation. Several research studies have been conducted on new techniques for changing packaging materials, as it is the root cause of better design in order to sell products. This packaging demand is shifting significantly, as Asia is projected to account for more than 40% of global demand. Plenty of the current packaging relies on highly performing plastics in the form <br/>of boxes, bags, cans, bottles, wrappers, and containers. Plastic-packaging materials become non-degradable waste that harms the well-being of the ecology by causing unnecessary landfills. <br/><br/>Therefore, the demand for renewable and biodegradable packaging materials has gradually due to their eco-friendly and sustainable nature. In this research, a biodegradable composite will be introduced for the food packaging industry using natural fibers. Natural fibers such as Hemp, Banana, Sisal, Coir, and Palmyra will be used as reinforcement to form the composite material. The mechanical attributes of Tensile, Compression, Impact, and Flexural Strength for distinct compositions will be studied experimentally, followed by conducting the necessary SEM analysis to obtain detailed observations of smaller grain sizes and material craters on the composite surfaces. The aforementioned results will demonstrate which composition will suit better than the others to replace modern packaging material.

**Design and development of a combined domestic food waste drying, crushing, and pelletizing machine (ID 213)**

Kurundukaarage Viraj Dilupa Ranathunga (University of Moratuwa) Kavishka Dinith Sandeepa Abesingha Herath Mudiyanselage (University of Moratuwa) Pasidu Sulochana Kuppasamilage (University of Moratuwa) J G A Saliya Jayasekara (University of Moratuwa) Sanjeeva Witharana (University of Moratuwa) Lihil Subasinghe (University of Moratuwa)

*Presenting Author:* Not yet updated

**Abstract**. Approximately one-third of globally produced food is discarded as waste, leading to significant environmental, economic, and social challenges. Food waste, being an organic material with high moisture content, undergoes rapid biodegradation, resulting in leachate formation and substantial contributions to landfill-generated greenhouse gas emissions. Conventional disposal methods remain largely ineffective in enabling efficient resource recovery, thereby underscoring the need for practical, decentralized solutions. In most of the developing countries, rapid urbanization coupled with limited waste management infrastructure has intensified the accumulation of organic waste at the household level. This represents a missed opportunity for material and energy recovery. To address this technological gap, the present study focuses on the design and development of a domestic-scale food waste dryer integrated with a solid biofuel pelletizing unit. The dryer is engineered to operate within typical domestic power constraints while ensuring controlled thermal conditions through forced convection. Key parameters, including airflow rate, temperature distribution, and residence time, are optimized to enhance drying performance. Experimental evaluation demonstrates significant moisture reduction (drying), improved storage stability (crushing), and increased energy recovery potential (pelletizing). The proposed system presents an affordable and scalable solution for decentralized food waste management, contributing to reduced environmental impact and promoting sustainable resource utilization.

**Design and development of a machine for producing plastic-based bricks from waste PET plastic.**
**(ID 156)**

Nethmi Dissanayake (University of Ruhuna)* Y. Sanath K. De Silva (University of Ruhuna)

*Presenting Author:* Nethmi Dissanayake (University of Ruhuna)

**Abstract**. Plastic waste management remains a critical environmental challenge in Sri Lanka, where an estimated 1.6 million tonnes of plastic waste are generated annually, yet only around 33% is properly collected and just 3% is recycled. Polyethylene terephthalate (PET) bottles are among the most persistent and abundant items in this waste stream. This paper presents the design and de-velopment of a small-scale, low-cost machine that converts waste PET plastic mixed with quarry dust into plastic-based paving blocks, offering a practical, community-level recycling route consistent with circular-economy princi-ples. Following a literature review, PET was selected as the most suitable waste plastic and a PET-to-quarry-dust mass ratio of 1:3 was adopted based on reported improvements in density, porosity and compressive strength. A machine configuration comprising a double-shaft shredder, a tiltable jacketed U-trough mixing chamber, a segmented paddle agitator and a vibrating gang-mould system was selected through a systematic design process. Engi-neering calculations were completed for the heating, mixing and vibration-compaction subsystems. A prototype paving block (200 × 100 × 60 mm) was manually fabricated, confirming the feasibility of the selected material com-position, and compression testing yielded a mean vibrated strength of 10.52 MPa. Numerical simulations were conducted to validate the inner wall tem-perature uniformity of the heating system and to verify the counter-circulation mixing behaviour of the paddle agitator.

**A Process-Integrated Value Chain Sustainability Framework for Upcycling Polypropylene Feedstocks in Fused Deposition Modeling**
**(ID 220)**

Armaan Mohamed (University of Kentucky) Nimesh Fernando (University of Kentucky)* R Sarvesha (University of Kentucky) James Caudill (University of Kentucky)

*Presenting Author:* Not yet updated

**Abstract**. Polypropylene (PP) is one of the world's most widely used thermoplastics, yet its recovery rate remains low despite its inherent recyclability. This study demon-strates a closed-loop processing route that converts post-consumer PP waste into fused deposition modeling (FDM) filament and functional components while evaluating their mechanical performance and sustainability. A sustainability as-sessment framework was employed to quantify the environmental, economic, and performance impacts of the proposed value-recovery strategy, including energy consumption, material utilization, processing efficiency, and waste diversion po-tential. Commercial PP bottle caps were used as surrogate feedstocks representa-tive of single-resin post-consumer waste streams and processed into FDM feed-stocks through shredding and subsequent extrusion. The resulting filament exhib-ited consistent dimensional quality, stable extrusion behavior, and reliable printa-bility, demonstrating its suitability as FDM feedstock, while printed specimens achieved approximately 81% of the ultimate tensile strength of those produced from commercial PP filament. Although waste processing and filament produc-tion introduced additional local processing, avoiding virgin resin production re-duced the overall environmental impact, yielding a more sustainable manufactur-ing pathway than conventional routes. These findings demonstrate that post-consumer PP can serve as a viable feedstock for additive manufacturing while advancing more sustainable and circular manufacturing practices.

| Thursday, September 24th, 15:25 - 16:45 | | | |
|---|---|---|---|
| **Industry Session III** | **End of Life Approaches** | **Manufacturing Process II** | **Social Sustainability** |
| King's Court I | King's Court II | Queen's Court I | Queen's Court II |
| | Practices, Challenges, and Opportunities Towards Increasing Recovery of Semiconductor Chip-Bearing Components and Subassemblies at End-of-Use (ID 87) | A Lifecycle-Based Lubrication Management Framework for Sustainable Industrial Operations (ID 24) | Navigating the Transition to Mercury-Free Technology through Behavioral Change: A Conceptual Framework for Sustainable Artisanal and Small-Scale Gold Mining (ID 118) |
| | Consideration of Upcycling Methods for Multilayer Flexible Films in the Packaging Industry (ID 103) | Investigation on the effect of Minimum Quantity Lubrication aerosol temperature on machining steels with sesame oil (ID 146) | A Human-Centric PFMEA Ontology Supporting Social Sustainability in Manufacturing (ID 170) |
| | From Polymer Additive Manufacturing Waste to Functional Paper Coatings (ID 29) | Investigation of the reuse of wire electrode in wire EDM for improved environmental performance (ID 163) | Development of a Simulation-Driven Framework for Prediction and Control of Industrial Noise Using Finite Element Analysis (ID 158) |
| | Process Diagnosis for Upcycling Post-Consumer Saline Bottles into Recycled Polypropylene Filament for Material Extrusion (ID 139) | | Evaluate the social sustainability of the Manufacturing Plant through Decent Work Concept (ID 197) |

# End of Life Approaches
# Thursday, September 24th, 15:25 - 16:45

## King's Court II

**Practices, Challenges, and Opportunities Towards Increasing Recovery of Semiconductor Chip-Bearing Components and Subassemblies at End-of-Use**
**(ID 87)**

Junwon Ko (Institute for Sustainable Manufacturing (ISM) and Department of Mechanical & Aerospace Engineering, University of Kentucky), Dhanraj Kharal (Institute for Sustainable Manufacturing (ISM) and Department of Mechanical & Aerospace Engineering, University of Kentucky), Fazleena Badurdeen (Institute for Sustainable Manufacturing (ISM) and Department of Mechanical & Aerospace Engineering, University of Kentucky), I. S. Jawahir (Institute for Sustainable Manufacturing (ISM) and Department of Mechanical & Aerospace Engineering, University of Kentucky), Ashley Hartwell (National Institute of Standards and Technology (NIST)), Buddhika Hapuwatte (National Institute of Standards and Technology (NIST))

*Presenting Author:* Junwon Ko (University of Kentucky)

**Abstract**. Semiconductor chips, or integrated circuits, are the backbone of modern electronic products. However, their resource-intensive manufacturing and dependence on critical materials create supply chain vulnerabilities and raise sustainability concerns. Interest in chip recovery at End-of-Use (EoU) has grown recently, yet it remains difficult to scale in practice. Recovering chip-bearing components and subassemblies, referred to as Microelectronic Components and Subassemblies (MCS), could offer a more pragmatic pathway to enhance the value of chip recovery. However, there is a lack of understanding of how EoU recovery operates within the global, multistakeholder supply chain. This work investigates current EoU recovery practices and challenges through engagement with industry experts from across the electronics supply chain in the U.S. Synthesizing information from interviews, this paper presents qualitative insights, outlining (1) current recovery practices, (2) reverse logistics processes, (3) compliance landscape, (4) data and information needs, (5) challenges and barriers, and (6) key drivers and opportunities. The paper further discusses key factors and future research needs to enable widespread operationalization of MCS recovery. This work can inform industry, academia, and decision-makers of critical gaps and conditions needed to advance MCS recovery. Furthermore, the insights presented contribute to scoping the measurement science for recovery practices, including the methods and metrics needed to support informed decision-making.

**Consideration of Upcycling Methods for Multilayer Flexible Films in the Packaging Industry (ID 103)**

Maurizio Fiorini (DICAM, University of Bologna), Anastasiia Timofeeva (DICAM, University of Bologna), Giampaolo Campana (DIN, University of Bologna)

*Presenting Author:* Maurizio Fiorini (University of Bologna)

**Abstract**. Multilayer flexible films play a crucial role in food packaging, notably by extending shelf life and thereby reducing food waste. However, because the polymers used in their individual layers are typically immiscible (e.g., aliphatic polyamides with polyolefins), recycling these materials within a circular economy framework remains challenging. The district of Castelnuovo Rangone, Modena, Italy is well known for meat processing, where small and medium-sized companies prepare boneless hams for slicing and packaging. These products are commonly packed in multilayer polyamide/polyethylene or polyamide/polypropylene/ polyethylene trays. Currently, the resulting packaging waste is collected and sent to incineration, contributing to resource depletion (since those plastics are derived from fossil fuels) and generating greenhouse gas emissions from transportation and combustion. An alternative scenario explored in this work involves the local collection of polyamide/polyolefin packaging waste and its processing at a nearby reclamation centre. The clean waste is shredded and compounded with a compatibilising agent before being pelletised. These pellets can be then extruded with/without the addition of virgin polyethylene to produce films sufficiently transparent, suitable for further application. An alternative upcycling process allows to produce gasoline tanks and other large containers used in agriculture, such as those used for rainwater storage. The overarching goal of the project is to transform multilayer plastic film waste into a valuable secondary raw material to manufacture usable plastic products. This contribution presents and discusses the technical aspects related to waste extrusion, compatibilisation, and the mechanical behaviour of the resulting blends. The sustainability performance of the proposed upcycling route is evaluated in terms of avoided emissions and additional indicators of overall environmental impact using Life Cycle Assessment (LCA).

**From Polymer Additive Manufacturing Waste to Functional Paper Coatings**
**(ID 29)**

Piia Kanto (Tampere University of Applied Sciences), Aku Malm (Tampere University of Applied Sciences), Katri Salminen (Tampere University of Applied Sciences)

*Presenting Author:* Piia Kanto (Tampere University of Applied Sciences)

**Abstract**. Selective Laser Sintering (SLS) produces significant polyamide 12 (PA12) powder waste, creating a challenge for sustainable material utilization. Only a fraction of the powder is sintered into parts during each build while the rest remains unused but preheated. Although unused powder can be recycled within the SLS process, repeated reuse eventually leads to polymer degradation, limiting its suitability for further SLS printing. Certain measures, such as powder refreshing, can extend its usability. However, the powder eventually becomes too degraded for reuse. This results in plastic waste with limited options for sustainable disposal or valorization. Currently, research has explored, for example, converting waste PA12 into filaments for FDM printing. Despite these advances, material upcycling remains limited. This study investigates a recycling route for SLS waste PA12 powder in paper coating applications. A PA12-containing coating dispersion was prepared and applied to paper substrates, followed by an evaluation of relevant paper properties. The results demonstrated that coating with recycled PA12 powder is technically feasible. The coating improved, for example, paper's barrier properties and tensile strength. These findings suggest that SLS waste PA12 powder may be valorized beyond traditional additive manufacturing reuse, contributing to circular economy approaches in polymer utilization.

**Process Diagnosis for Upcycling Post-Consumer Saline Bottles into Recycled Polypropylene Filament for Material Extrusion**
**(ID 139)**

N. Liyanawaduge (University of Peradeniya), V. Mahawaduge (University of Peradeniya), D. Pabasara (University of Peradeniya), P. Gamage (University of Peradeniya)

*Presenting Author:* N. Liyanawaduge (University of Peradeniya)

**Abstract**. Post-consumer polypropylene (PP) saline bottles are a recurring hospital waste stream in Sri Lanka. This study examined whether cleaned bottles could be converted into filament for fused deposition modelling (FDM) using a low-cost strip-fed pull-extrusion route. A two-level factorial investigation considered nozzle temperature (140°C/150°C), pulling velocity (4 mm/s/5 mm/s), cooling fan condition, and strip width (8 mm/10 mm). Temperature had the strongest effect on mean filament diameter ($p = 0.002$), followed by strip width ($p = 0.030$). Pulling velocity and fan condition were not significant at the 95% level. Diameter variability did not show a statistically significant factor, although the fitted trend indicated higher variability at 150°C. Later 150°C trials were not printable because strands snapped during extrusion, so printability was tested using 140°C filament. A nested Gage R&R study gave 11.01% study variation and a number of distinct categories (ndc) of 12. Hollow cubes of approximately 17 mm height were printed from 8 mm and 10 mm strip-width filament; the 10 mm case showed more continuous visual deposition, while the 8 mm case showed a side-wall discontinuity. The results support laboratory-scale feasibility and identify temperature and strip width as the main process levers, without claiming optimized production, mechanical performance, or commercial readiness.

# Manufacturing Processes II
# Thursday, September 24th, 15:25 - 16:45

## Queen's Court I

### A Lifecycle-Based Lubrication Management Framework for Sustainable Manufacturing (ID 24)

Julia Heggemann (SKF Lubrication Systems Germany GmbH), Guillaume Amilien (SKF FRANCE S.A.), Yongrong Li (SKF Lubrication Systems Germany GmbH)

*Presenting Author:* Yongrong Li (SKF Lubrication Systems Germany GmbH)

**Abstract**. Industrial lubrication is essential to asset reliability but is often managed through manual, time-based, and inconsistently executed practices. This leads to excessive lubricant use, premature failures, unplanned downtime, and unnecessary environmental impact. This paper presents a lifecycle-based lubrication management framework as a structured approach to improve reliability, efficiency, and sustainability in manufacturing systems. The framework builds on the 5Rs of lubrication—right lubricant, right amount, right point, right method, and right time—and extends them with a 6th R, right connectivity, to support digital traceability and more consistent execution. It integrates lubrication engineering, automatic lubrication systems, IoT-based monitoring, cloud analytics, and circular solutions for oil regeneration and reuse. In this way, lubrication management can be positioned as part of an Industry 4.0 approach to maintenance and sustainable manufacturing. The paper shows that systematic, digitally enabled lubrication management can support sustainable manufacturing by reducing waste, improving asset performance, and strengthening lifecycle-based maintenance strategies. The discussion is developed from industrial practice but is positioned within broader themes of reliability engineering, predictive maintenance, and circular resource management.

### Investigation on the Effect of Minimum Quantity Lubrication Aerosol Temperature on Machining Steel with Sesame Oil (ID 146)

S. Thenusa (University College of Jaffna, University of Vocational Technology, University of Moratuwa), R.K.P.S. Ranaweera (University of Moratuwa), H.K.G. Punchihewa (University of Moratuwa)

*Presenting Author:* S. Thenusa (University College of Jaffna, University of Vocational Technology, University of Moratuwa)

**Abstract**. Heat generation during metal cutting is inevitable and is traditionally controlled using large volumes of cutting fluids (CFs), which pose economic, environmental, and health concerns. Minimum Quantity Lubrication (MQL) has emerged as a sustainable alternative by significantly reducing CF consumption while maintaining effective machining performance. The use of biodegradable plant-based oils, such as sesame oil, further enhances environmental sustainability. This study investigates the effects of aerosol temperature of sesame oil-based MQL when turning AISI D2 steel. An MQL delivery system was developed to supply sesame oil aerosol at a constant flow rate. Experiments were conducted by varying the cutting speed, feed rate, depth of cut, and aerosol temperature. Tool nose wear, surface roughness, energy consumption, and material removal rate were used as key performance indicators to evaluate machining performance. The ANOVA indicated that CF application method was the dominant factor, accounting for 65% of the overall performance variation. Moreover, Taguchi–Grey Relational Analysis identified MQL at 17°C as the optimal temperature, achieving a 36% improvement over dry cutting. These findings demonstrate that sesame oil-based MQL when operating at optimal aerosol temperatures can enhance machining efficiency while reducing fluid use and energy consumption, supporting sustainable manufacturing.

**Reusing Brass Wire Electrode in WEDM for Improved Environmental Performance**
**(ID 163)**

K. Kamalaruban (University College of Jaffna, University of Vocational Technology), J.R. Gamage (Department of Mechanical Engineering, University of Moratuwa)

*Presenting Author:* K. Kamalaruban (University College of Jaffna, University of Vocational Technology)

**Abstract**. The brass wire electrode (BWE) is widely used in wire electric discharge machining. Its application is limited to a single use due to the formation of pits and micro-cracks during machining at extremely high temperatures. Therefore, the cost of the BWE constitutes the largest proportion of the operational cost. Moreover, the demand for wire EDM (WEDM) process is expected to increase significantly due to precision machining applications. The increasing demand for a single-use wire electrode addresses the importance of research in its reusability. This paper explores the reuse of BWE recovered after WEDM process for improved environmental performance. The used wire is subjected to appropriate post-treatment processes to restore the microstructure, enabling potential reuse. Two treatments: (1) stress-relieved annealing at 300°C, 350°C, and 400°C, and (2) zinc-coated diffusion annealing at 250°C, 300°C, and 350°C. Surface structure analysis using SEM images indicated that the treatments enhance the surface integrity by reducing the size and number of pits. Dimensional analysis revealed that stress-relieved annealing caused increasing diameters, whereas zinc-coating exhibited negligible influence on the diameter. The LCA results indicated that treatment 1 outperformed treatment 2 with improvements of 50% and 38% compared to virgin wire environmental performance respectively.

# Social Sustainability
# Thursday, September 24th, 15:25 - 16:45

## Queen's Court II

**Navigating the Transition to Mercury-Free Technology through Behavioral Change: A Conceptual Framework for Sustainable Artisanal and Small-Scale Gold Mining**
**(ID 118)**

Roberta Zulfhi Surya (Department of Industrial Engineering, Universitas Andalas, Department of Industrial Engineering, Universitas Putra Indonesia YPTK), Elita Amrina (Department of Industrial Engineering, Universitas Andalas), Insannul Kamil (Department of Industrial Engineering, Universitas Andalas)

*Presenting Author:* Roberta Zulfhi Surya (Andalas University)

**Abstract**. Artisanal and small-scale gold mining (ASGM) plays a vital role in supporting livelihoods and contributing to the global gold supply. However, ASGM is also a significant source of mercury pollution, which poses serious risks to ecosystems and human health. Despite efforts such as mercury bans, financial incentives, and the introduction of mercury-free technologies, many ASGM communities continue to rely on mercury. This suggests that technological solutions alone are insufficient, as behavioral, social, and contextual factors significantly influence the adoption of technology. This study proposes a conceptual framework explaining the transition toward mercury-free technology through behavioral changes in alluvial ASGM. The framework integrates the Technology Acceptance Model and the Theory of Planned Behavior, complemented by demographic and sociocultural characteristics. It examines how perceived risk and technology adaptability affect perceived usefulness and ease of use, shaping miners' attitudes. These attitudes, along with subjective norms and perceived behavioral control, influence behavioral intention and actual adoption. Furthermore, environmental concern strengthens the relationship between attitude and intention, while concerns about legal enforcement reinforce the link between intention and behavior. The framework emphasizes the importance of behavioral dynamics in enabling sustainable mining transitions and offers insights for designing more effective policies and interventions.

**A Human-Centric PFMEA Ontology Supporting Social Sustainability in Manufacturing**
**(ID 170)**

Anubhab Majumder (Dept. of Mechanical and Production Engineering, Aarhus University, Grundfos A/S), Badrinath Veluri (Grundfos A/S), Rami Mansour (Dept. of Mechanical and Production Engineering, Aarhus University), Devarajan Ramanujan (Dept. of Mechanical and Production Engineering, Aarhus University, Dept. of Civil and Mechanical Engineering, Technical University of Denmark)

*Presenting Author:* Anubhab Majumder (Grundfos Holding A/S)

**Abstract**. Human-centricity and sustainability are central pillars of Industry 5.0. Yet, Process Failure Mode and Effects Analysis (PFMEA) frameworks typically treat human deviations under the broad category of 'human error,' limiting their ability to represent complex socio-technical factors that shape operator performance. This simplification constrains process understanding and improvement, particularly in human skill-intensive manufacturing contexts. This paper presents a human-centric PFMEA ontology that formally specifies the representation of human-factor related failure causes within the context of failure analysis. Building on human error classifications and related performance shaping factors (PSFs), the ontology augments the traditional PFMEA frameworks by explicitly incorporating human operator-related determinants. This enhancement includes a structured taxonomy of human error types and the associated PSFs that contribute causally to their occurrence. Developed using the METHONTOLOGY framework and implemented in Protégé, the ontology provides a machine interpretable vocabulary for consistently capturing the PFMEA data within complex manufacturing processes. By embedding human-centric knowledge directly into PFMEA, the proposed ontology advances social sustainability by enabling a more accurate understanding of operator needs, constraints, and systemic influences, and lays the groundwork for future extensions toward data-driven and automated Human-centric PFMEA.

**Development of a Simulation-Driven Framework for Prediction and Control of Industrial Noise Using Finite Element Analysis**
**(ID 158)**

Saditha K.B. Dissanayake (Department of Mechanical Engineering, University of Moratuwa), R.K.P.S. Ranaweera (Department of Mechanical Engineering, University of Moratuwa)

*Presenting Author:* Saditha Dissanayake (University of Moratuwa)

**Abstract**. Noise pollution in industrial environments creates major problems for both workplace performance and the surrounding community. Although passive noise insulation remains one of the most practical control approaches in industry, the complex acoustic behaviour of factory environments makes the design and evaluation of such solutions unsustainable using conventional trial-and-error methods. This study develops a simulation-driven framework for the prediction and control of industrial noise using finite element analysis (FEA). The framework integrates acoustic modelling, measurement-supported validation, and comparative evaluation of passive control strategies. The investigation focuses on the most common three categories of passive noise control: barrier or boundary-wall systems, wall and roof absorption treatments, and multi-layer wall or cavity-based insulation systems. The study also emphasises the importance of measurement-supported validation, using frequency-resolved acoustic data to improve the reliability of simulation results. By integrating acoustic modelling, validation, and comparative performance evaluation, this work contributes a practical methodology for simulation-assisted industrial noise mitigation and provides a basis for improved design, optimisation, and decision-making in passive acoustic control.

**Evaluate the social sustainability of the Manufacturing Plant through Decent Work Concept**
**(ID 197)**

K.G.A.I. Kodithuwakku (University of Peradeniya), H.D.P. Premarathne (University of Peradeniya), Asela K. Kulathunga (University of Exeter)

*Presenting Author:* Priyadarshani Premarathne (University of Peradeniya)

**Abstract**. Present-day global supply chains increasingly demand traceability across both environmental and social dimensions to comprehensively assess product sustainability. While significant progress has been made in evaluating environmental sustainability, social sustainability in manufacturing environments remains comparatively underexplored and inadequately measured. Existing initiatives such as green jobs, Decent Work, and Social Life Cycle Assessment (S-LCA) address fragments of this challenge, yet no integrated, general purpose evaluation tool exists that holistically quantifies social sustainability performance across multiple dimensions in manufacturing or process plant settings. This paper presents the design, structure, and preliminary validation of a comprehensive social sustainability evaluation framework for manufacturing employees, synthesizing the International Labour Organization Decent Work indicators, the UNEP-SETAC S-LCA guidelines, and SDG-aligned Key Performance Indicators (KPIs). The framework was empirically validated at a leading porcelain manufacturing enterprise in Sri Lanka, using a quantitative descriptive approach combining cross-sectional surveys. Findings reveal strong performance in work-life balance (97%) and social dialogue (92%), while adequate earnings and productivity (70.2%) and fair treatment (82%) require targeted intervention. The proposed framework provides a replicable, sector-neutral instrument for benchmarking social sustainability in manufacturing supply chains and guiding alignment with the 2030 SDGs.

| Friday, September 25th, 09:30 - 11:30 | | | |
|---|---|---|---|
| **Sustainable Manufacturing Systems** | **Sustainable Business Models** | **Sustainable Energy Transition and Development** | **Sustainable Consumer Goods** |
| King's Court I | King's Court II | Queen's Court I | Queen's Court II |
| An event-based semantic framework for modeling sustainability impacts in product design and manufacturing systems<br>(ID 26) | Development of Industrial Decarbonisation Roadmaps: A Workshop-based Approach and Procedure<br>(ID 93) | Advancing Vocational Excellence in Hydrogen Education: A Pedagogical Framework from the H2VE Project<br>(ID 180) | Design and Development of a Decision Support Framework to Reconfigure the Vegetable Supply Chain to Enhance Sustainability<br>(ID 148) |
| A Methodology for Developing a Procedural Model for the Integration of Sustainability Aspects into Factory Planning<br>(ID 31) | Sustainability-Oriented Business Model Transformation Index for Manufacturing SMEs<br>(ID 134) | Hydrogen enrichment for coal mine gas power generation<br>(ID 80) | A Comparative Sustainability Assessment of Different Cosmetic Jar Designs<br>(ID 42) |
| Capacity-Driven Decision Support Model for the Early Assessment of Product Variants in Sustainable Factory Systems<br>(ID 33) | Foresight Design Thinking for Circular Business Model Innovation in Smart Building Management Systems: Evidence from Thailand<br>(ID 20) | Life Cycle Assessment of a Mini-Grid Hydrogen System in Ghana<br>(ID 207) | A Sustainable Lean Approach for Waste Reduction in Bread Production Processes<br>(ID 120) |
| GMP and Halal Assurance Assessment for Sustainable Food Manufacturing in SMEs<br>(ID 190) | Support Model for SMEs in the Process of Transition Toward Sustainability – A Case Study from the SMERF Project<br>(ID 123) | EXPLORING THE CONGRUENCE AMONG THE DRIVERS OF INDUSTRY 4.0 IMPLEMENTATION IN THE INDIAN ENERGY SECTOR: AN ISM-MICMAC ANALYSIS<br>(ID 48) | Design and Validation of a Mixed-Mode Solar Dryer with IoT Integration for Post-Harvest Preservation in Sub-Saharan Africa<br>(ID 86) |
| Challenges for the Absolute Sustainable Design of (De-)Manufacturing Systems<br>(ID 51) | Phase-based Framework for Lifecycle Management in Manufacturing-as-a-Service Environments<br>(ID 126) | Unit-Level Flexibility for Refinery Resilience and Sustainability: Two-Stage Stochastic Multi-Objective Optimization<br>(ID 104) | Design Guideline for Cosmetic Product Packaging Aiming Reduced Environmental Footprint<br>(ID 34) |

# Sustainable Manufacturing Systems
# Friday, September 25th, 09:30 - 11:30

## King's Court I

### An event-based semantic framework for modeling sustainability impacts in product design and manufacturing systems
**(ID 26)**

Fabian Romano Rusch (Helmut Schmidt University), Thorsten Schmidt (Helmut Schmidt University), Wilke Willems (Helmut Schmidt University), Niels Demke (Helmut Schmidt University), Frank Mantwill (Helmut Schmidt University)

*Presenting Author:* Fabian Romano Rusch (Helmut Schmidt University)

**Abstract**. Developing sustainable and circular products requires coordinated decision-making between product design and manufacturing systems while accounting for long-term sustainability impacts. Early design choices propagate through production, use, and end-of-life phases and interact with external factors such as policy changes and energy systems. Existing assessment approaches, including Life Cycle Assessment, provide valuable metrics but are largely retrospective and struggle to represent dynamic cause–effect relationships triggered by decisions across product variants. This paper presents an event-based semantic framework integrating an ontology and a machine-readable syntax for structured impact modeling to support early-stage decision-making on sustainability impacts across product design decisions and manufacturing life cycle phases. The framework distinguishes between discrete change events, such as design or policy decisions, and phase events representing development, production, use, and end-of-life stages. Impacts are structured as primary, secondary, and tertiary effects and linked to temporal validity and baseline scenarios, enabling transparent tracing of causal chains from design decisions to system-level sustainability consequences. Implemented in OWL 2, the ontology is designed for interoperability with digital engineering environments and life cycle databases. A case study from electric vehicle development illustrates how the framework supports comparison of product variants in concrete design and manufacturing decision scenarios.

### A Methodology for Developing a Procedural Model for the Integration of Sustainability Aspects into Factory Planning
**(ID 31)**

Jan Phillip Koch (Institute of Production Systems and Logistics / Leibniz University Hannover), Tanya Jahangirkhani (Institute of Production Systems and Logistics / Leibniz University Hannover), Matthias Schmidt (Institute of Production Systems and Logistics / Leibniz University Hannover)

*Presenting Author:* Jan Phillip Koch (Leibniz University)

**Abstract**. Factory planning decisions fundamentally shape a factory's ecological, economic, and social sustainability performance over its entire life cycle. Yet existing approaches fail to provide a procedural framework that systematically links all three sustainability dimensions to planning phases, decision points, and interdisciplinary responsibilities. This paper presents the research methodology for developing such a model — a necessary prerequisite to its empirical derivation and, as such, an independent scientific contribution. Grounded in four formulated requirements and structured into five sequential work packages, the methodology addresses the identification of sustainability objectives, the modelling of causal interdependencies between these objectives and factory objects, the identification of potentials, the derivation of discipline-specific task profiles, and the integration of phase-bound sustainability gates as iterative control mechanisms. Together, these work packages establish a transparent and replicable pathway toward holistic sustainability integration in factory planning and provide the foundation for future model development and validation.

**Capacity-Driven Decision Support Model for the Early Assessment of Product Variants in Sustainable Factory Systems**
**(ID 33)**

Mehmet Demir (Institute of Production Systems and Logistics / Leibniz University Hannover), Tobias Kleinewächter (Institute of Production Systems and Logistics / Leibniz University Hannover), Manuel Ludwig (Institute of Production Systems and Logistics / Leibniz University Hannover), Matthias Schmidt (Institute of Production Systems and Logistics / Leibniz University Hannover)

*Presenting Author:* Mehmet Demir (Institute of Production Systems and Logistics / Leibniz University Hannover)

**Abstract**. In a dynamic market environment, increasing product variety is a key strategy for maintaining competitiveness. However, this trend often leads to uncontrolled complexity in factory systems, posing not only economic risks but also causing significant ecological inefficiencies. Due to the multitude of complex interactions and far-reaching consequences, the effects of introducing new product variants are often not fully transparent, which in practice frequently leads to a systematic underestimation of variant-related costs and irreversible planning errors. Unprofitable product variants bind valuable resources and threaten the economic viability of companies. It is therefore crucial to distinguish between value-adding and value-destroying product variants before the start of production. This paper presents a systematic decision support model, which enables an early-stage differentiation by comparing factory and product variant profiles. By preventing irreversible investments and addressing the phenomenon of cost remanence, the model contributes to resource efficiency and the sustainability of factory systems.

**GMP and Halal Assurance Assessment for Sustainable Food Manufacturing in SMEs**
**(ID 190)**

Nilda Tri Putri (Department of Industrial Engineering, Universitas Andalas), Azahra Prety Conita (Department of Industrial Engineering, Universitas Andalas), Hary Fandeli (Department of Industrial Engineering, Universitas Andalas)

*Presenting Author:* Nilda Tri Putri (Universitas Andalas)

**Abstract**. Food safety and halal assurance are vital for sustainable manufacturing in home-based food SMEs, which often lack facilities and formal structures. Sustainable systems require structured controls, standardized procedures, and ongoing monitoring to ensure reliability and market confidence. This study assesses Good Manufacturing Practices and Halal Assurance System implementation in a home-based food SME via observation, interviews, and checklists. Findings reveal low compliance 37.8% for Good Manufacturing Practices and 33.3% for Halal Assurance System highlighting unsystematic processes. Key gaps include process control, facility layout, documentation, training, and monitoring, with partial adherence in hygiene and halal ingredients. We propose an integrated Good Manufacturing Practices – Halal Assurance System framework to redesign systems through SOPs, documentation, layout optimization, and training, fostering structured, reliable, and sustainable operations with enhanced food safety and halal assurance in small-scale industries.

**Challenges for the Absolute Sustainable Design of (De-)Manufacturing Systems**
**(ID 51)**

Kristian König (Universität des Saarlandes), Michael Vielhaber (Universität des Saarlandes)

*Presenting Author:* Kristian König (Universität des Saarlandes)

**Abstract**. Manufacturing and demanufacturing systems represent key leverage points for sustainable development, yet most sustainable design approaches still focus on relative impact improvements rather than performance against absolute environmental or social limits. Absolute sustainability requires such systems to operate within the Earth's safe operating space (environmental ceiling) while meeting minimum social thresholds (just space, social floor), and remain economically viable under these tightening constraints. This paper argues that transferring absolute sustainability concepts from product systems to (de)manufacturing systems introduces methodological challenges as manufacturing assets are multi-functional enabling infrastructures shared across several product systems along their life cycles. We synthesize four key challenge clusters for absolute target-setting and evaluation: downscaling environmental and social budgets, rebound and throughput effects that can negate per-unit improvements, time-critical pathways of such long-lived assets, and, indirect contributions to basic need provisioning and "do-no-harm" social minima across global supply chains. An illustrative robotic tool-change gripper case demonstrates how absolute sustainability conclusions can reverse under alternative sharing principles, functional units, and output assumptions. We conclude by outlining research needs to integrate absolute targets into early-stage (de)manufacturing system design and decision support, explicitly addressing multifunctionality, rebound effects, and responsibility allocation.

# Sustainable Business Models
# Friday, September 25th, 09:30 - 11:30

## King's Court II

### Development of Industrial Decarbonisation Roadmaps: A Workshop-based Approach and Procedure (ID 93)

Felix Budde (Fraunhofer-Institute for Production Systems and Design Technology), Ronald Orth (Fraunhofer-Institute for Production Systems and Design Technology), Lina Stockmann (Fraunhofer-Institute for Production Systems and Design Technology)

*Presenting Author:* Felix Budde (Fraunhofer IPK)

**Abstract**. Industrial decarbonisation requires site-specific, structured planning approaches and procedures that translate long-term climate targets into feasible implementation pathways. This paper presents a systematic approach and procedure for developing industrial decarbonisation roadmaps, adapted from conventional technology roadmapping. While conventional technology roadmapping primarily focuses on aligning technological developments with markets and product strategies, the proposed approach expands this logic by integrating decarbonisation targets and technologies as well as business model implications into a participatory multi-criteria decision framework tailored to industrial transformation contexts. The proposed method is based on a literature review and iterative co-creation workshops involving interdisciplinary teams. Roadmap development follows three sequential steps: (1) assessment of the current production system, GHG emissions profile, and strategic and operational targets, (2) identification of relevant decarbonisation technologies, associated business model implications, implementation risks, and (3) multi-criteria evaluation and prioritization of technologies to construct a coherent decarbonisation pathway. To ensure consistency and comparability across applications, a procedure for decarbonisation roadmap development is derived. The results provide a transparent and replicable framework that supports companies in structuring decarbonisation decisions under technical, economic, and organizational constraints.

### Sustainability-Oriented Business Model Transformation Index for Manufacturing SMEs (ID 134)

Joanna HELMAN (Wroclaw University of Science and Technology), Maria ROSIENKIEWICZ (Wroclaw University of Science and Technology), Mariusz CHOLEWA (Wroclaw University of Science and Technology), Mateusz MOLASY (Wroclaw University of Science and Technology)

*Presenting Author:* Joanna Helman (Wrocław University of Science and Technology)

**Abstract**. Manufacturing SMEs face increasing pressure to redesign and implement sustainable business models in response to environmental, economic, and social challenges. Despite the growing body of research classifying sustainable and circular business model archetypes, structured tools supporting their prioritization remain limited. This study proposes a Business Model Transformation Index (BMTI) as a metric-based framework for evaluating and prioritizing sustainability-oriented business model transformation pathways. The index integrates three dimensions central to sustainable business model implementation: organizational readiness, feasibility derived from implementation complexity, and sustainability impact across environmental, economic, and social domains. The framework is applied to a portfolio of 31 sustainable business models identified in manufacturing SMEs. Each model is assessed using a transparent scoring scheme, and BMTI values are calculated at both model and pattern levels, enabling portfolio-level comparison across nine sustainability-oriented transformation patterns. Results reveal meaningful differentiation in transformation potential, with BMTI values ranging from 4 to 12. Efficiency-driven and organizational infrastructure models demonstrate higher prioritization potential, whereas innovation-intensive and socio-transformative models require greater organizational maturity.

**Foresight Design Thinking for Circular Business Model Innovation in Smart Building Management Systems: Evidence from Thailand**
**(ID 20)**

Kallaya Tantiyaswasdikul (Faculty of Architecture and Planning, Thammasat University, Rangsit Campus)

*Presenting Author:* Kallaya Tantiyaswasdikul (Thammasat University)

**Abstract**. Circular business model innovation is increasingly important in the built environment as digital technologies enable new approaches to lifecycle management and resource optimization. However, circular economy research has predominantly focused on material flows and upstream manufacturing, providing limited insight into how digital and service-oriented firms create circular value during the use and operation phases of the asset lifecycle. This study addresses this gap by examining how Foresight Design Thinking—an integrative approach combining strategic foresight and design thinking to explore alternative futures and support innovation under uncertainty—supports circular business model development in smart building solutions. Using a qualitative single-case study of Aiyara Harn Co., Ltd., a Thai firm specializing in building management systems, the research investigates lifecycle-oriented service innovation in the built environment. The findings demonstrate that Foresight Design Thinking enables the firm to transition from a technology provider to a lifecycle-oriented service integrator by enhancing energy efficiency, extending asset longevity, and supporting adaptive building operations through data-driven services and predictive maintenance. This study contributes to circular business model and sustainable manufacturing scholarship by introducing a foresight-driven approach to service-oriented circular innovation, thereby extending the circular value creation beyond production processes toward data-driven service systems in rapidly urbanizing contexts.

**Support Model for SMEs in the Process of Transition Toward Sustainability – A Case Study from the SMERF Project**
**(ID 123)**

Maria ROSIENKIEWICZ (Wroclaw University of Science and Technology), Joanna HELMAN (Wroclaw University of Science and Technology), Mateusz MOLASY (Wroclaw University of Science and Technology), Mariusz CHOLEWA (Wroclaw University of Science and Technology)

*Presenting Author:* Maria Rosienkiewicz (Wroclaw University of Science and Technology)

**Abstract**. Despite the growing number of sustainability frameworks, small and medium-sized enterprises (SMEs) still lack practical tools supporting the implementation of sustainability-oriented transformation. Existing approaches are often too generic or designed for large organisations, limiting their applicability in SMEs. This paper addresses this research gap by presenting a support model for SMEs transitioning toward sustainability, developed within the SME Ready for the Future (SMERF) project and co-financed by the Interreg Central Europe programme. The study combines a literature review with a case study conducted within the SMERF project. The empirical research involved over 180 companies from seven countries: Austria, Croatia, Germany, Hungary, Italy, Poland, and Slovakia. Based on the identified barriers and needs of SMEs, a comprehensive and modular support model was developed. The model integrates the SMERF Diagnosis Tool, the Inspiration Knowledge Base, the InnoGreen market concept, an Individual Support Programme, and dedicated training activities. The findings confirm the practical applicability of the model and its potential for replication across different national and sectoral contexts. The proposed framework contributes to the development of structured and practice-oriented instruments supporting SMEs in their transition toward sustainability.

**Phase-based Framework for Lifecycle Management in Manufacturing-as-a-Service Environments (ID 126)**

Götz Müller (Chair of Quality Science, Technical University of Berlin), Maurice Meyer (Chair of Quality Science, Technical University of Berlin), Viviane Sarwar (Chair of Quality Science, Technical University of Berlin), Felix Lentz (Chair of Quality Science, Technical University of Berlin), Roland Jochem (Chair of Quality Science, Technical University of Berlin)

*Presenting Author:* Götz Müller (TU Berlin)

**Abstract**. The digitalization of manufacturing has catalyzed the emergence of platform-based models such as Manufacturing-as-a-Service (MaaS), enabling flexible, resource-efficient and circular production. However, ensuring sustainable operation of MaaS platforms requires comprehensive lifecycle consideration across products, processes and systems. To achieve this, current Lifecycle Management (LCM) approaches are considered as a basis for deriving specific lifecycle phases for MaaS platforms that are aligned with the platform's value chain and tailored to its operational logic. Buildings on this, the paper develops a MaaS-specific, phase-oriented LCM framework that systematically captures the dimensions of a MaaS platform. In addition, the study explores the role of digital product passports in enabling lifecycle transparency and data exchange within sustainable MaaS ecosystems. Therefore, a use case from the automotive industry is introduced, focusing on Returnable Transport Items (RTIs) as key elements of circularity.

# Sustainable Energy Transition and Development
# Friday, September 25th, 09:30 - 11:30

## Queen's Court I

### Advancing Vocational Excellence in Hydrogen Education: A European Framework and Guide for Educators (ID 180)

Loredana Tiedke (Bochum University of Applied Sciences), Surya Kumar Devarajan (Bochum University of Applied Sciences), Semih Severengiz (Bochum University of Applied Sciences)

*Presenting Author:* Surya Kumar Devarajan (Bochum University of Applied Sciences)

**Abstract**. The transition to a sustainable energy future demands professionals with practical knowledge and teaching skills in hydrogen. Despite growing demand, no consolidated, evidence-based curriculum framework for vocational education and training (VET) in this field has existed to date. The European Erasmus+ project "H2VE – Hydrogen Valley Vocational Excellence Hub" addresses this gap with the Guide for Trainer Curriculum: a new original European framework designed for hydrogen VET that is transferable to further regions, e.g. Africa. Its key contributions include a modular architecture supporting both micro-credentials and full qualifications across EQF levels 3-8 and a concrete operationalization of Bloom's Revised Taxonomy for hydrogen education, providing trainers with actionable guidance for learning outcome design, teaching method selection and assessment. The framework integrates digital tools, inclusive learning strategies, and adaptive learning systems within a single, adaptable reference. Validated through consortium review and stakeholders engagement, it is currently applied within the project to develop training materials for implementation across partner networks. Disseminated through a dedicated webinar series, the Guide fosters knowledge exchange and promotes an evidence-based approach to building the competencies the hydrogen economy requires.

### Hydrogen Enrichment for Coal Mine Gas Power Generation: A Simulation-Based Study on Efficiency Improvement and Operational Limits (ID 80)

Clemens Biet (Technische Universität Berlin, Chair of Integrated Modelling of Efficient Powertrains), Sören Krebs (Technische Universität Berlin, Chair of Integrated Modelling of Efficient Powertrains)

*Presenting Author:* Clemens Biet (Technische Universität Berlin)

**Abstract**. Utilization of methane from abandoned coal mines is a profitable climate protection method. Uncontrolled and otherwise unused methane emissions are converted to carbon dioxide through combustion. Considering the higher climate impact factor of methane, this has significant potential to reduce CO2 equivalent emissions. Simultaneously, methane release from coal mines is being used for profit-oriented power generation. After years of operation, coal mine gas power generation (CMGPG) faces the challenge of steadily declining methane content. This leads to less efficient operation of the methane combustion engines, resulting in lower electrical power output. In the future, the methane content of mine gas might drop below the threshold of stable engine operation. This paper investigates the idea of hydrogen enrichment for CMGPG. Two main advantages are improved combustion efficiency and prolonged CMGPG operation. The corresponding technical options are being explored by thermodynamic modelling of the combustion process of hydrogen enriched mine gas. Calculations are based on an operational 1.2 MW facility. Based on the simulation results, the study estimates the potential for engine efficiency improvement through the addition of hydrogen at 3%pt. as well as an extended duration of operation by 14 years considering the observed decline in methane content.

**Life Cycle Assessment of a Solar Mini-Grid Integrated Hydrogen System in Sub-Saharan Africa: A Scenario Comparison**
**(ID 207)**

Laura Semrau (Sustainable Technologies Laboratory, Bochum University of Applied Sciences), Eric Faulhammer (Sustainable Technologies Laboratory, Bochum University of Applied Sciences), Semih Severengiz (Sustainable Technologies Laboratory, Bochum University of Applied Sciences)

*Presenting Author:* Laura Semrau (Bochum University of Applied Sciences)

**Abstract**. Decentralized renewable mini-grids are increasingly deployed in Sub-Saharan Africa to address unreliable and fossil-fuel-dependent electricity supply. While hydrogen offers potential for long-term energy storage, its environmental impacts remain under-explored. This study carries out a life cycle assessment (LCA) in accordance with ISO 14040/44 to evaluate the environmental impacts of a proton exchange membrane (PEM) hydrogen system integrated into a solar-powered mini-grid in Tema, Ghana. Multiple scenarios compare different storage configurations and levels of hydrogen system maturity integrated into the mini-grid. The results identify PV modules as main environmental hotspot in most categories, accounting for up to 33% of the total impact. Within the hydrogen system, storage bundles dominate all impact categories with up to 79% due to their substantial mass and high steel content. In low maturity hydrogen scenarios, electrolyzer maintenance also contributes notably. The low maturity base scenario shows the highest environmental impacts within the mini-grid scenarios. However, higher system maturity significantly reduces these impacts through improved efficiency and optimized operation. Although hydrogen enables full system autonomy, battery-only storage has the lowest overall impact.

**EXPLORING THE CONGRUENCE AMONG THE DRIVERS OF INDUSTRY 4.0 IMPLEMENTATION IN THE INDIAN ENERGY SECTOR: AN ISM-MICMAC ANALYSIS**
**(ID 48)**

Ganesh Prasad Shukla (Guru Ghasidas Vishwavidyalaya (A Central University), Bilaspur), Kaushal Prasad (Guru Ghasidas Vishwavidyalaya (A Central University), Bilaspur), Pranav Gupte (Guru Ghasidas Vishwavidyalaya (A Central University), Bilaspur)

*Presenting Author:* Not yet updated

**Abstract**. The energy sector holds a significant position in economic growth, power security and sustainable development across the globe. The emergence of fourth industrial revolution, known as Industry 4.0 (I4.0), represents a paradigm shift toward digitally enabled, intelligent and sustainable industrial systems. There are several elements which plays a crucial role in the adoption of I4.0 technologies, commonly referred to as ‘drivers’. Notwithstanding its importance, there is a notable lack of empirical studies that precisely explored the I4.0 drivers within the energy sector. Addressing this gap, the present study investigates the key drivers of I4.0 adoption in the Indian energy sector and examines their structural inter-relationships. A comprehensive literature review was conducted to identify potential drivers, of which ten were shortlisted through validation by academic experts and industry practitioners. Interpretive Structural Modelling (ISM) was employed to analyze the congruence among these drivers, followed by MICMAC analysis to categorize them based on driving and dependence power. The results reveal that leadership commitment, policy support and financial capability are the primary driving elements, while human capital, digital integration and business model agility emerge as dependent drivers. The study provides valuable insights for policymakers and managers seeking effective I4.0 implementation in the energy sector.

**Unit-Level Flexibility for Refinery Resilience and Sustainability: Two-Stage Stochastic Multi-Objective Optimization**
**(ID 104)**

Alperen Bal (College of Engineering and Technology, American University of the Middle East), Oumayma Hamlaoui (College of Engineering and Technology, American University of the Middle East), Hakan Tozan (College of Engineering and Technology, American University of the Middle East)

*Presenting Author:* Alperen Bal (American University of Middle East)

**Abstract**. While macro-level supply chain models effectively mitigate network-wide disruptions, they often overlook the complex operational dependencies within individual refinery operations. This study introduces a two-stage stochastic multi-objective optimization framework to enhance the unit-level resilience and sustainability of high-capacity mega-refineries. By treating disruptions as stochastic probabilistic events at the unit level (e.g., Crude Distillation and Sulfur Recovery Units), the model balances three competing objectives: minimizing expected total costs, minimizing expected environmental sulfur compliance risk, and maximizing resilience through minimized expected unmet demand. A hybrid solution approach utilizing the Non-dominated Sorting Genetic Algorithm II (NSGA-II) embedded with an exact linear programming recourse solver is developed. The findings demonstrate that strategic first-stage investments in critical unit spares and product buffer inventories can significantly mitigate second-stage environmental penalties without causing market shortages. The resulting Pareto-optimal policies provide a generalized decision-support mechanism for global refinery operators to navigate the trade-offs between economic efficiency and stringent environmental regulations during disruptive events.

# Sustainable Consumer Goods
# Friday, September 25th, 09:30 - 11:30

## Queen's Court II

### Design and Development of a Decision Support Framework to Reconfigure the Vegetable Supply Chain to Enhance Sustainability
**(ID 148)**

Chethana Chandrasiri (University of Peradeniya), Subodha Dharmapriya (University of Peradeniya), Asela K. Kulatunga (University Exeter)

*Presenting Author:* Chethana Chandrasiri (University of Peradeniya)

**Abstract**. In an era in which majority of industries are competitive to achieve sustainability the transition from intuition based decision making to data driven decision making is a necessity. Lack of data driven decision making has led to supply chain inefficiencies and post-harvest losses ultimately resulting in supply demand imbalance and price volatility. In the Sri Lankan main stream vegetable supply chain overall 20% of the produced vegetables get wasted creating frequent price volatility and supply-demand imbalance. The suggested analytical framework to reconfigure vegetable supply chain combines optimization and simulation tools along with real time and past data. Deterministic, Stochastic and Dynamic optimization have been combined with discrete event simulation in order to generate optimal configurations capturing uncertainties and the dynamic nature. The suggested analytical framework has been tested for the existing vegetable supply chain in Sri Lanka to support product flow, flow direction, packing type selection, vehicle type selection and delivery scheduling to reduce cost, waste and emission further enhancing smooth operations at economic centers. The suggested analytical framework is capable to enhance sustainability and efficiency, reduces post-harvest losses, and improves resilience, via informed stakeholder decision-making ultimately establishing supply demand equilibrium.

### A Comparative Sustainability Assessment of Different Cosmetic Jar Designs
**(ID 42)**

P.M.M.P. Thennakoon (University of Moratuwa), H.P. Karunathilake (University of Aalto), J.R. Gamage (University of Moratuwa)

*Presenting Author:* P.M.M.P. Thennakoon (University of Moratuwa)

**Abstract**. The global cosmetic packaging industry has surged in recent years amid rising demand for cosmetics and personal care products, yet it is associated with significant environmental drawbacks. This study aims to conduct a comparative life-cycle assessment (LCA) and propose a packaging efficiency index (PEI) for cosmetic containers. Four types of commercially available Polypropylene (PP) screw lid jars are examined. Material efficiency was quantified as the PEI, defined as the ratio of filled packaging to empty packaging weight. In addition, a cradle-to-gate LCA was conducted with a functional unit defined as the packaging required to deliver a unit amount of content (moisturiser). Global warming potential (GWP) was selected as the primary impact indicator. Life cycle inventory data for plastic production were obtained from the published literature. The results reveal that PEI values range from 2.1 to 3.1. A higher PEI and a lower GWP indicate potential benefits for logistics on a per-functional basis. Sensitivity analysis confirms that GWP scales linearly with packaging weight (±10-20% variation), validating the robustness of the findings. Overall, the findings demonstrate that integrating a weight-based efficiency indicator into LCA provides a practical and robust approach to assessing the sustainability of cosmetic packaging.

**A Sustainable Lean Approach for Waste Reduction in Bread Production Processes**
**(ID 120)**

Elita Amrina (Department of Industrial Engineering, Universitas Andalas), Athiya Aufa (Department of Industrial Engineering, Universitas Andalas)

*Presenting Author:* Elita Amrina (Universitas Andalas)

**Abstract**. Improving production efficiency is critical for food manufacturing industries facing increasing competition and sustainability challenges. Inefficiencies often arise from production waste, leading to higher costs and negative environmental and social impacts, such as excessive energy use and worker fatigue. Preliminary observations in a bread production company identified key wastes, including transportation, defects, and overproduction, along with high electricity consumption and ergonomic risks. This study aims to assess production waste using a sustainable lean approach that integrates lean manufacturing tools with sustainability considerations. Sustainable Value Stream Mapping (SVSM) is applied to analyse production flows from economic, environmental, and social perspectives. Process Activity Mapping (PAM) identifies value-added and non-value added activities, while a fishbone diagram determines root causes of waste. Failure Mode and Effect Analysis (FMEA) is used to prioritize critical risks and improvement actions. The results provide a comprehensive understanding of waste sources and sustainability issues in the production process. The proposed improvements are expected to reduce non-value added activities, lower energy consumption, improve working conditions, and enhance overall efficiency. This study offers practical insights into implementing sustainable lean practices in small-scale food manufacturing industries.

**Design and Validation of a Mixed-Mode Solar Dryer with IoT Integration for Post-Harvest Preservation in Sub-Saharan Africa**
**(ID 86)**

W. Herbert (University of Zimbabwe), A. Musarurwa (University of Zimbabwe), L. Gudukeya (University of Zimbabwe)

*Presenting Author:* Not yet updated

**Abstract**. Post-harvest losses in sub-Saharan Africa reach 30–40% of harvested crops annually, threatening food security and smallholder farmer livelihoods. This paper presents the design, fabrication, and field validation of a mixed-mode solar dryer integrating passive solar thermal collection with active ESP32-based fan-assisted airflow control and real-time IoT monitoring via the Blynk cloud platform. A solar collector (1.2 m × 0.8 m matte-black aluminium absorber beneath 4 mm tempered glass) was coupled with a 30 W solar PV-powered fan array and three DHT11 sensor nodes at inlet, mid-chamber, and outlet positions. Load cells provided continuous gravimetric tracking. Field experiments conducted in Harare (17.8°S, 1,490 m elevation) with fresh cabbage (Brassica oleracea) demonstrated a dryer chamber temperature of 52.4°C average (31.6°C above ambient), maintaining relative humidity at 35–50%. The solar dryer reduced drying time from 4.00 h (open-sun baseline) to 2.08 h, a 48% reduction in drying time corresponding to a 1.85× increase in average drying rate, achieving 85% moisture removal. Moisture ratio decay followed exponential kinetics ($R^2$ = 0.982), consistent with Fick's second law of diffusion. The IoT subsystem logged 1,497 data points at 5-second intervals with 100% WiFi uptime and less than 3-second cloud latency. Total capital cost was USD 163. Annual savings of USD 319 from reduced spoilage, labour, and throughput improvements yield a payback period of 6.1 months. Over a 10-year lifespan, the system avoids 5.2 tonnes of $CO_2$ compared to electric and diesel drying alternatives. The design addresses SDG 2, SDG 7, SDG 12, and SDG 13, and is replicable using locally available materials and open-source electronics.

**Design Guideline for Cosmetic Product Packaging Aiming Reduced Environmental Footprint (ID 34)**

H.M.I.K. Herath (Department of Mechanical Engineering, University of Moratuwa, Department of Materials Technology, Faculty of Technology, Rajarata University of Sri Lanka), J.R. Gamage (Department of Mechanical Engineering, University of Moratuwa)

*Presenting Author:* H.M.I.K. Herath (University of Moratuwa)

**Abstract**. The cosmetic industry is a significant contributor to plastic waste in Sri Lanka, with extensive use of plastic-based packaging where recycling and waste management remain limited. This study proposes a design guideline for cosmetic product packaging aiming reduced environmental footprint. This investigates the life cycle environmental impacts of three widely used cosmetic packaging types, namely a plastic bottle with flip cap, a collapsible squeeze tube, and a thick-bottom plastic tub. The assessment is carried out using SimaPro LCA software, with the ReCiPe 2016 Endpoint (H) method. The study evaluates each packaging under functional units of 100ml volume package and a fast-moving SKU. The assessment considered packaging material production, manufacturing, filling and sealing of product and end of life management. The findings reveals that the impact of material type and the quantity significantly outweighs the energy consumption for stages after production. A design guideline is developed based on the LCA results, recommending the use of low impact material types, mono-material structures, lightweight designs, compatibility with local recycling systems and optimized SKU sizes. The proposed guideline gives practical support for designers and manufacturers in making cosmetic packaging with reduced environmental footprint.

Technische Universität Berlin
Institute for Machine Tools and Factory Management (IWF)
Chair of Corporate Sustainable Development
Prof. Dr.-Ing. Holger Kohl

University of Moratuwa
Prof. JR Gamage