Book of abstracts

rev2025 | Resource Efficient Vehicles Conference
23 – 25 September 2025

Version 6

Graz, 22.09.2025

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Preamble

Dear rev2025 community!

Welcome to rev2025, focusing on ***Enabling Circular and Decarbonized Vehicle and Transport Solutions.***

We, the organizing committee, are delighted to welcome you to Graz from 23 – 25 September. We have received 45 eligible contributions that will be presented on conference day 1 and conference day 2 at our venue, the Hotel Weitzer.

To get more in-detailed insights about the conference programme, the respective sessions and allocated contributions, this Book of Abstracts serves as a comprehensive guide. The Book of Abstracts shall provide participants with further information about the session and contribution content, giving a sneak peak into the topics and latest research findings discussed at rev2025.

The structure of the Book of Abstract follows the conference programme in terms of sessions with their designated contributions.

To be noted: this document does not contain the submitted full papers and extended abstracts. Those will be provided via the conference tool Oxford Abstract and after the conference in the electronic conference proceedings.

As we come together to exchange ideas, foster collaboration, and inspire innovation, we hope this Book of Abstracts will serve as both a practical tool and a source of inspiration.

Thank you for joining us at rev2025. We look forward to vibrant discussions and inter- and transdisciplinary exchange.

Warm regards,

your organizing committee

Rupert J. Baumgartner

Josef-Peter Schöggl

Katharina Berger

Conference programme – overview

Day 1 (23.09.2025)			
from 8:30 onwards		Registration – available the entire day	
From	**To**	**Room: Styria**	**Room: Riverside**
09:00	09:30	Welcome to and opening of rev2025	
09:30	10:15	Keynote I Speaker: Johanna Nylander, GKN Aerospace	
10:15	10:30	Morning coffee break (Room: Lobby)	
10:30	12:00	Advancing Sustainable Battery Design: Materials, Circularity, and Environmental Impact	Enhancing Resource Efficiency and Circularity in the Transport System
12:00	13:00	Lunch break (Room: Engelreich)	
13:00	13:45	Keynote II Speaker: Matthias Asplund, Trafikverket	
13:45	14:00	Break	
14:00	15:30	Life Cycle Management in early-vehicle design: Frameworks and Life Cycle Optimization approaches	Digital Product Passports for Sustainable Mobility Solutions
15:30	16:00	Afternoon coffee break (Room: Looby)	
16:00	17:30	Innovative Rail Vehicle Design: Lightweight Structures, Efficiency, and Integrated Functions	Advancing Energy Efficiency and Sustainability in Mobility Systems
End of first day			
Day 2 (24.09.2025)			
from 8:30 onwards		Registration – available until last keynote of the day	
From	**To**	**Room: Styria**	**Room: Riverside**
09:00	09:45	Keynote III – Round Table	

09:45	10:00	Morning coffee break (Room: Lobby)	
10:00	12:00	Data-driven circular and sustainable vehicle management	Innovations in Sustainable Transport
12:00	13:00	Lunch break (Room: Engelreich)	
13:00	13:45	Keynote IV Speaker: Beatriz Ildefonso, European Commission, DG Research & Innovation	
13:45	14:00	Break	
14:00	15:30	Bridging Sustainability and Design I	Societal perspective in decarbonized transport solutions
15:30	16:00	Afternoon coffee break (Room: Lobby)	
16:00	17:30	Bridging Sustainability and Design II	
17:30	17:45	Closing of second day	
from 18:30 onwards		Conference Dinner @Kunsthaus Café	
Day 3 (25.09.2025)			
From	**To**		
09:00	12:00	Excursion @AVL List GmbH **Meeting point: Hans-List-Platz 1, 8020 Graz at 8:45**	
13:30	15:00	City of Graz Tour Meeting point: Weitzer	

Session content - overview

Day 1

Morning Session 1.1: Advancing Sustainable Battery Design: Materials, Circularity, and Environmental Impact

10:30 - 12:00 Tuesday, 23rd September, 2025

Chair:
Hanno Bachler-Udier, AVL List GmbH

Location:
Weitzer, Room “Styria”

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19 An innovative and sustainable battery case design made from wood, steel and cork

Georg Baumann[1], Markus Wagner[1], Harald Sehrschön[2], Patricia Caleffa[3], Thomas Krenke[4], Alexander Harrich[5], Claudia Mair-Bauernfeind[6], Florian Feist[1]

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[4]Innovationszentrum W.E.I.Z., Weiz, Austria

[5]AVL List GmbH, Graz, Austria

[6]Institue of Environmental System Sciences, University of Graz, Graz, Austria

Abstract

State-of-the-art battery cases in electric vehicles are typically constructed from aluminium and/or steel. Aluminium in particular is a material, which is known for its high CO_2 footprint and global warming potential (GWP). In the previous research project BioLIB!, a wood-steel hybrid battery case incorporating cork-based cell holders was developed. Compared to an all-metal battery case, it demonstrated a significantly reduced environmental footprint, while meeting essential requirements such as crash- and fire- related safety. In the follow-up project SMADBatt (Sustainable MAterials and Design for electric vehicle batteries), the wood-steel hybrid battery case is being further optimised, to increase the ecological and economic benefits. These improvements include the use of secondary raw materials, including recycled wood and cork material, in conjunction with biomass from forest thinning, which is so far almost exclusively used for energy purposes. This involves indentifying accessible material streams in proper quality, quantity and price to adapt and upgrade these materials for high value applications, such as in the automotive industry. Furthermore, the design of the battery case should facilitate easy dismantling and disassembly through detachable connections including triggerable adhesive systems. In addition, the thermo-management of the batteries should also be optimised in order to increase the overall efficiency of the electric vehicle. Customised solutions will be developed, taking into account a range of drive- and climate-cycle scenarios and the related cell ageing. This will not only improve the overall energy balance, but also the lifetime of the batteries and the electric vehicle, making it more sustainable and environmentally friendly. In summary SMADBatt

supports the transformation of mobility towards bio- and circular-economy, through increased energetic and raw material resource efficiency.

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31 Design for disassembly: The influence of EV battery pack designs on environmental impact and circularity beyond the first life cycle

Tasya Oka[1], Maximilian Schinagl[2], Paul Krassnitzer[1], Markus Fasching[2], Claudia Mair-Bauernfeind[1], Tobias Stern[1]

[1]*University of Graz, Graz, Austria*

[2]*TU Graz, Graz, Austria*

Abstract

In recent years, lithium-ion (Li-ion) batteries have become essential to the global automotive industry, transforming vehicle power solutions. As the market for these batteries continues to grow, battery disposal has become a significant concern. In light of the climate crisis and resource scarcity, the traditional linear economic model of "take-make-dispose" is becoming unsustainable. This practice is increasingly being replaced by the restorative framework of the Circular Economy (CE). To effectively implement CE principles, an eco-design strategy, such as designing for disassembly, can be integrated at the beginning of product development of Li-ion battery pack. This approach ensures that battery packs can be dismantled efficiently, facilitating sustainable practices—such as recycling, repair, and reuse—at the end of their life. This study aims to examine the environmental benefits and trade-offs, such as those occurring between different life cycle stages or indicators, associated with design for disassembly. This will be achieved through a comparative analysis of three battery packs with different levels of dismantlability. A crash scenario is included in the initial product life cycle which allows the extension of environmental impact analysis beyond the design, use and disposal phase by including the potential for reuse and repair of each battery pack. To achieve this, a life cycle assessment (LCA) incorporating system expansion by considering two life cycles will be conducted. Given that the focus of LCA is to evaluate environmental impacts, circularity assessments will be conducted to highlight the effects of design-for-circularity measures. The outcome of this study will provide an overview of the environmental impact and circularity of design for disassembly not only on the first product life cycle but also on the potential second life cycle by considering repair and reuse.

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7 The potential of reducing greenhouse gas emissions of lithium-ion battery production in different geographic scenarios

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[2]*Institute of Automotive Engineering, Graz University of Technology, Graz, Austria*

Abstract

Battery electric vehicles (BEVs) have emerged as a promising solution for the transition towards sustainable mobility, offering the potential to decrease greenhouse gas (GHG) emissions and reducing dependence on fossil fuels. However, while BEVs offer the potential for reduced emissions during operation, battery manufacturing processes are associated with considerable carbon footprints. Furthermore, the choice of

cathode material significantly influences the environmental impact created by lithium-ion battery production. The current state-of-the-art route of production of lithium-ion batteries occurs mainly outside of Europe and to a large extent in countries owning a greenhouse gas-intensive electricity mix, resulting in a significant quantity of emissions generated. As the European Green Deal promotes sustainable production and use of batteries within the EU, this paper investigates GHG emissions generated by a hypothetical battery manufacturing scenario occurring in Europe, using the framework of Life-Cycle Assessment, and compares them to the conventional production route occurring globally and mainly in Asia. The results are retrieved for different battery types and for both, a hypothetical European Route and a Conventional Route, per 1 kWh of battery pack produced. The cathode chemistries under scope are NMC111, NCA and LFP, representing the state of the art of today's automotive battery technology. The outcomes of this paper highlight that the European production route shows a significant potential for greenhouse gas reduction (approximately 40 % for all battery chemistries) in comparison to the Conventional Route. Besides highlighting the high relevance of local material sourcing and battery production, the results also outline the necessity of using renewable energy sources for the entire process of lithium-ion battery production. In this way, a holistic consideration of influencing factors supports a detailed discussion and derivation of recommendations with the target to make the production of lithium-ion batteries more sustainable.

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44 Influence of early-stage design choices on the environmental performance of repurposed lithium-ion batteries

Anna Spindlegger[1], Aleksander Jandric[1], Ricardo Gabbay De Souza[2,3], Stefanie Prenner[4], Florian Part[1]

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Abstract

Lithium-ion batteries (LIBs) are a key technology in decarbonisation, particularly for their use in electric vehicles (EVs) and battery energy storage systems (BESS). Nevertheless, their production is associated with significant environmental impacts. Repurposing LIBs after their use in EVs for less demanding applications, such as BESS, has the potential to reduce these impacts. However, current repurposing efforts face several technical challenges, often requiring the replacement of key components. For example, the module casing might be damaged during disassembly, while the battery management system (BMS) is typically replaced because it is not programmed for stationary applications and contains sensitive data belonging to original equipment manufacturers (OEMs). This study examines how specific early-stage design choices influence the environmental impacts of second-life applications. A life cycle assessment (LCA) of a BESS equipped with repurposed LIBs was conducted, evaluating different repurposing scenarios based on the reuse or replacement of the BMS and module casing. The results revealed a superior environmental performance of second-life BESS compared to new systems in four out of five analysed impact categories. The lowest impacts were identified when both the module casing and the BMS were reused, while the highest impacts were observed when both components were replaced. These results underscore the importance of designing LIBs to enable component reuse and facilitate a more sustainable repurposing process. A "circular by design" approach could involve avoiding adhesive connections to prevent damage to battery components, particularly the module casing, while maintaining safety.

Additionally, integrating a BMS reset function, as suggested in the EU battery regulation 2023/1542, could enhance the sustainability of repurposed LIBs without compromising data confidentiality.

Morning Session 1.2: Enhancing Resource Efficiency and Circularity in the Transport System

10:30 - 12:00 Tuesday, 23rd September, 2025

Chair:
Jenny Jerrelind, KTH Royal Institute of Technology

Location:
Weitzer, Room “Riverside”

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16 Promoting Electrification of Regional Rail Transport through Shared Charging Infrastructure with Road Vehicles

Amir Torkiharchegani[1], Mats Alaküla[1], Francisco J. Márquez-Fernández[1], Libor Lochman[2], Rickard Persson[3], Martin Tunér[4], Christoffer Ahrling[4], Marcel Scharmach[5]

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Abstract

The electrification of regional rail systems offers a promising path to reducing greenhouse gas emissions in transportation. However, full electrification is often economically unfeasible in low-traffic areas. Battery-powered trains provide an alternative, but large battery sizes—needed for long non-electrified stretches—result in higher costs and increased CO_2 emissions from battery manufacturing. This study explores strategies to address these challenges by promoting shared charging infrastructure between rail and road vehicles. The first scenario considers static charging stations installed at selected railway stations. These enable partial recharging, reducing battery size and deep discharge cycles, which extends battery lifespan and lowers environmental impact. However, in low-traffic regions, such infrastructure may be underutilized and economically inefficient. To improve utilization, a shared-use model is proposed, where electric buses, trucks, and passenger EVs also access these stations. This approach leverages growing EV charging demand to justify investment and increase station efficiency, while fostering an integrated network across transport modes. The second scenario examines the implementation of Electric Road System (ERS) technologies, such as those by Elonroad, which enable in-motion charging. Deploying ERS on lanes shared by both road and rail vehicles—especially in space-constrained areas like bridges—maximizes infrastructure use and maintains safety and accessibility. Together, these scenarios highlight the potential of shared infrastructure to overcome the limitations of standalone rail electrification. By improving economic viability, reducing environmental impact, and supporting multimodal sustainability goals, the proposed strategies advance cleaner transport solutions. The work will present the benefits of this integrated approach, emphasizing its role in enabling cost-effective, sustainable electrification of regional transport networks.

48 Launching circular pilot lines in the Meuse-Rhine region to boost circularity of Electric Vehicle production

Bert Dexters, Nataliya Babych, Mohammad Meraj Alam, Xiao Ma, Philip Eyckens

Flanders Make, Lommel, Belgium

Abstract

Running until mid 2027, the CYPRESS INTERREG project will establish a highly circular and resource-efficient supply chain within electric vehicle production that spans a cross-border ecosystem within the Meuse-Rhine region. The goal is to reduce the ecological footprint and promote long-term sustainability in the automotive sector by fostering collaboration among SMEs and larger enterprises within the value chain, from material supply and recycling to manufacturing and testing. CYPRESS will create a collaborative platform for over 150 companies and regional stakeholders, driving innovation in circular materials, processes, and business models. The project will co-develop three pilot production lines for key automotive components, including (1) a battery module of an electric car tailored for refurbishment and repair; (2) a hydrogen tank for the fuel cell electric vehicle that is partly produced with recycled carbon fiber; and (3)) a gearbox for electric vehicle drivetrains. The project aim is to establish at least one physical pilot production line through cross-border cooperation, leveraging regional private investments through a grant scheme. As part of the transition, the project will also focus on developing assessment studies, technological toolkits, and training programs for technicians, engineers, and managers. By boosting a circular economy that is efficient in usage of materials and energy, this project effectively promotes the Green Transformation. The regional SMEs that are often innovation drivers forms the main project target group, but also larger enterprises will benefit. The targeted companies are those active in the automotive value chain: material supply and recycling, design, simulation and engineering, manufacturing, assembly and testing. In addition, SMEs in circular materials, processes and business models may grow their business in the automotive sector. A strong involvement of the regional industry is embedded within each activity of this project.

11 Exploring the landscape of circularity indicators: A systematic review with focus on nano- and micro indicators for the assessment of biobased materials and products

Paul Krassnitzer, Johanna Fank, Tasya Oka, Claudia Mair-Bauernfeind

Department of Environmental System Sciences, Graz, Austria

Abstract

The transition to a circular economy necessitates robust metrics to assess the effectiveness of circularity measures. This paper systematically explores proposed indicators, focusing on the assessment of circularity at both the material- and product level. A literature review, employing the snowballing technique and a targeted search within the date range of 2022 to 2025, identified 303 indicators, of which 120 were deemed eligible. These indicators were evaluated based on their consideration of R-strategies, biobased materials, assessment scale, dimensionality (economic, environmental, social), and more. Most indicators focus on the environmental dimension and assess circularity at the product level. The R-strategies, Recycle, Reuse, and Recover, are most commonly accounted for, while strategies like Rethink and Refuse are rarely considered. Notably, many indicators appear to focus on recyclability, potentially biasing assessments

towards less environmentally preferable options. Preliminary results highlight the need for indicators that better credit more effective R-strategies to facilitate the transition towards a circular economy. Further work will investigate the suitability of these indicators for biobased materials and apply a selected set to a case study of a novel wood-hybrid battery compartment for benchmarking purposes.

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25 Multi-Regional Input-Output analysis to improve Resource Efficiency in traction battery value chains

Julius Ott

University of Graz, Graz, Austria

Abstract

Battery Electric Vehicles (BEVs) are seen as important contributors to the decarbonization of human mobility and therefore undoubtedly provide significant value. However, BEVs are also highly resource intensive throughout their life cycle, with various options for improvement, from material extraction to End of Life (EoL). This is especially true for the battery, where much of the resource use is obscured within its complex value chain. Providing the same value to humanity with fewer resources would be highly beneficial on a global scale. The idea of Resource Efficiency (RE) is to generate the most monetary benefit (e.g., GDP, value added) from the utilization of a unit of resource. This concept appears in various policy areas related to the circular economy, bioeconomy, and the United Nations Sustainable Development Goals (SDGs). To answer the research question, 'What are the potentials to increase the RE in traction batteries?', the research consists of several distinct steps: The final demand for electric equipment is isolated from other demands, represented in the Multi-Regional Input-Output (MRIO) tables of Exiobase 3 (Stadler et al., 2025) and its impacts on resource consumption are analysed. After that, the status quo RE is presented. Finally, the RE is tested on its sensitivity to modifications of the driver of its denominator as identified by Pothen (2017) by setting up an alternative scenario. Due to the sectoral resolution, the research doesn't differentiate between different chemical elements, however the results offer valuable guidance on the drivers of resource consumption in the traction battery value chain and the potentials for achieving higher RE. More specifically, this research provides insights such as preferred manufacturing locations and “material hotspots” for policymakers and industry stakeholders aiming to improve the RE of BEVs in general and batteries in particular.

Afternoon Session 1.1: Life Cycle Management in early-vehicle design: Frameworks and Life Cycle Optimization approaches

14:00 - 15:30 Tuesday, 23rd September, 2025

Chair:
Ciarán J. O'Reilly, KTH Royal Institute of Technology

Location:
Weitzer, Room "Styria"

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40 The energy consumption of a heavy-duty ground vehicle subjected to extreme crosswind

Tural Tunay[1], Lars Drugge[2], Ciarán J. O'Reilly[2,3]

[1]Adana Alparslan Turkes Science and Technology University, Faculty of Engineering, Department of Mechanical Engineering, Adana, Turkey

[2]KTH Royal Institute of Technology, Department of Engineering Mechanics, Stockholm, Sweden

[3]The Centre for ECO2 Vehicle Design at KTH, Stockholm, Sweden

Abstract

The road transport sector, a major consumer of global energy, relies predominantly on oil-based fuels and contributes significantly to greenhouse gas emissions. Enhancing fuel efficiency through improved vehicle aerodynamics is essential for sustainable mobility. However, crosswind disturbances compromise aerodynamic performance by increasing drag and rolling resistance, particularly for heavy-duty vehicles. This study investigates the impact of extreme crosswind on vehicle energy consumption and dynamic behaviour by considering driver steering response under extreme conditions at different delay times. A two-way coupled aerodynamic and vehicle dynamics simulation framework is employed to capture these interactions. The findings highlight the critical role of driver skills, i.e., prompt steering by driver effectively mitigates energy losses, whereas delayed or abrupt corrections exacerbate rolling resistance through pronounced tyre slip angles. For example, delayed steering response of the driver (e.g., 1.0 second delay) increases energy consumption by 77% when compared to 44% maximum increase for prompt steering of the driver. These results underscore the complex interplay between aerodynamic forces and driver-induced dynamics in shaping vehicle energy efficiency under crosswind conditions.

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50 Advancing High-Temperature PEM Fuel Cells for Heavy-Duty Applications: Performance, Sustainability, and Life Cycle Assessment Insights from the MEAsureD Project

Max Triebel[1], Anja Rammer[2], Moritz Duft[2], Nikolaos Theodoropoulos[1], Emory De Castro[1], George Paloumpis[1], Hanno Bachler-Udier[2]

[1]Advent Technologies, Platani, Greece

[2]AVL List, Graz, Austria

Abstract

The EU-funded Horizon 2020 project "MEAsureD" aims to enhance the performance and durability of high-temperature proton exchange membrane fuel cells (HT PEMFC) for heavy-duty vehicle applications by integrating experimental research with advanced simulation-based modeling. One part of the project is to evaluate the environmental impact of existing FC technologies and explore how systems operating at higher temperatures can offer a cleaner and more sustainable alternative. To assess these benefits, a meta-study on FC sustainability, synthesizing literature on resource consumption, greenhouse gas emissions, recyclability, and circularity is performed. This study provides a quantitative evaluation of the current status of the environmental footprint of PEMFC systems. By consolidating data from previously conducted life cycle assessment (LCA) studies, the meta-study establishes benchmark values for key environmental indicators, including global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), and abiotic depletion potential (ADP). These benchmarks together with the LCA on a reference HT PEMFC in the present study form the baseline for evaluating the sustainability advancements of Advent Technologies HT PEMFC systems during the MEAsureD project. The LCA results show high indicator values for GWP and EP, and low values for AP and ADP compared to the literature benchmarks. Impact reduction potentials which can be harnessed through reaching MEAsureD KPIs, including reduced platinum loading and increased power density, are found to be significant. Drawing on Advent Technologies expertise, the project will refine critical technical parameters to define a high-performance HT PEMFC that meets economic and environmental sustainability objectives. The project aims to deliver an improved system of up to TRL 4. Through these efforts, the MEAsureD project contributes to the broader adoption of FC technology, supporting its integration into sustainable mobility solutions and advancing clean energy innovations in transport.

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39 A life cycle optimization framework for heavy-duty vehicles: conceptualization and use cases

Nicolas J. Katzer, Josef-Peter Schöggl and Rupert J. Baumgartner

Christian Doppler Laboratory for Sustainable Product Management enabling a Circular Economy, Department of Environmental Systems Sciences, University of Graz, Graz, Austria

Abstract

The environmental impacts of heavy-duty vehicles (HDVs) are a growing concern due to technical difficulties to reduce emissions. This research proposes a Life Cycle Optimization (LCO) framework for

HDVs, integrating mathematical optimization algorithms for environmental impacts into product development to enable more eco-efficient and eco-effective product system designs.

The framework builds upon the framework for life cycle engineering (LCE) but integrates an optimization loop based on recent vehicle optimization studies within a five-step process. It hereby systematically links product system design with the life cycle inventory, impact assessment, evaluation of target fulfilment, and optimization algorithm. All elements are based on the preliminary findings of a structured literature review (n= 315) coupled with an expert workshop (n=8) to ensure alignment between HDV development challenges and life cycle optimization requirements. The framework is pre-tested on a theoretical vehicle development (a mid-class 40t long-haul HDV for the European market) to provide a first proof-of-concept. It is capable to guide development choices toward an eco-effective design while maintaining functional performance. Its modular and customizable structure allows for adaptation to different system levels and product configurations (top-down and bottom-up), supporting a dynamic evolvement of the optimization focus corresponding to the actual HDV development process. Due to the iterative optimization process entailing a multi-level perspective of the product system (the engineering processes as well as the physical manifestation of the product and its background system), the proposed framework enables key insights into how component-level optimizations manifest on the HDV's life cycle performance, emphasizing the role of data-driven decision-making in vehicle development. Future research should aim to refine the matching of HDV development phases onto data requirements for the life cycle optimization via case studies, streamlining the evaluation of target fulfilment, and integrating the spatiotemporal specificity.

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53 Investigation of new ion-pair based membranes for carbon-neutral propulsion of heavy duty vehicles

Heiko Luis Hirschmann[1], Florian Tritscher[1], Nikolas Theodoropoulos[2], Viktor Hacker[1], Vasiliki Zogali[2], George Paloumpis[2], Emory De Castro[2], Merit Bodner[1]

[1]*Institute of Chemical Engineering and Environmental Technology, Graz, Austria*

[2]*Advent Technologies, Patras, Greece*

Abstract

Hydrogen fuel cells are a promising carbon-neutral technology for powering heavy duty vehicles (HDVs) and could help decarbonize the transport sector. High temperature proton exchange membrane fuel cells (HT-PEMFCs) are a type of fuel cell that can be operated with cheaper hydrogen because of the high operating temperature and require less heat exchangers than low temperature (LT-)PEMFCs due to the larger temperature gradient to the environment. Recently, new materials such as ion-pair based membranes have been developed to overcome phosphoric acid leaching that is limiting the lifetime of state-of-the-art phosphoric acid doped polybenzimidazole (PBI) based membranes. In this study, the new ion-pair based membranes as well as reference PBI membranes are evaluated with 100 h accelerated stress tests (ASTs) that mimic the real-life operation in HDVs . The materials are characterized by common in-situ methods such as polarization curves and electrochemical impedance spectroscopy (EIS) as well as ex-situ methods such as scanning electron microscopy (SEM). Further, methods for the quantification of phosphoric acid in the effluent water are applied to study the phosphoric acid leaching and demonstrate the capabilities of the new materials.

Afternoon Session 1.2: Digital Product Passports for Sustainable Mobility Solutions

14:00 - 15:30 Tuesday, 23rd September, 2025

Chair:
Rupert J. Baumgartner, University of Graz

Location:
Weitzer, Room “Riverside”

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8 From literature to practice: Understanding researcher perspectives towards social issues in digital battery passports

Martina Zimek, Katharina Berger, Julius Ott

University of Graz, Graz, Austria

Abstract

The Digital Product Passport (DPP) is a cornerstone of the 2024 Ecodesign Regulation for Sustainable Products. It is an innovative tool designed to improve the transparency and sustainability of product value chains. The DPP acts as a digital identity card that promotes the circularity of products and strengthens compliance with legal standards and regulations. In response to the upcoming European battery regulation that will mandate digital battery passports (DBPs) for industrial and electric vehicle batteries (EVBs) from 2026, this study addresses the neglected integration of social aspects that are crucial for the sustainable management of the EVB value chain. DBPs are innovative tools designed to digitally document comprehensive details of EVBs, encompassing technical specifications, circularity data, and information on sustainability throughout their lifecycle. Although environmental aspects have been included in the conceptualization of DBPs, social factors have not been sufficiently analysed or incorporated, despite their importance for a holistic sustainability perspective in the transport sector. Therefore, this study uses a mixed-methods approach to investigate the integration of social issues into the value chain of EVBs in the context of DBPs. Through a systematic review of the scientific literature, coupled with insights from academic-led workshops, the present study identifies pressing social issues that are essential for a socially sustainable EVB value chain. The results highlight the most pressing social issues relevant to a DBP, e.g., health and safety issues of workers and local communities, fair wages, child labour, local employment, and education and training of workers in the EVB value chain. In this case, the study highlights the researcher's view that social issues must be an integral part of DBP development to ensure that holistic aspects of sustainability are addressed, the overall management of EV value chains is improved, and ethical industry practices are supported.

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9 Digital vehicle passports for circular value chains: preliminary concept and use cases

Katharina Berger, Rupert J. Baumgartner

University of Graz, Graz, Austria

Abstract

This paper presents a preliminary concept for a digital vehicle passport (DVP) of an electric vehicle (EV), abstracting major vehicle components by delineating information requirements needed to support respective circular and sustainable product management. Furthermore, three practical DVP use cases are presented, representing major vehicle life cycle phases. The concept development was driven by a systematic stakeholder mapping, enabling to identify key stakeholders of the EV (component) value chain(s). A systematic literature review enabled the identification of sustainable and circular EV (component) management practices and information requirements for respective support. Those information requirements were synthesized in an abductive approach. This resulted in a DVP concept comprising three main information categories. Furthermore, the developed concept emphasizes a DVP orchestration via subsuming digital product passports (DPPs) of EV components (e.g., digital battery passport, digital e-motor passport, digital tyre passport, etc.), exploiting data synergies. This paper contributes to current DPP literature in a sustainable product management context, as it presents the first conceptualization of a complex multi-component product. Thus, it distinguishes itself from current DPP research, that mainly focuses on energy storage systems or the built environment. The paper further holds practical relevance for regulators and practitioners as it highlights sustainable product management use cases and respective information requirements.

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51 Digital Battery Passport: Driver for a Sustainable E-Mobility

Martin Rothbart[1], Udo Schulz[1]

[1]AVL List GmbH, Graz, Austria

Abstract

The automotive industry's shift towards electrification has led to a significant increase in the proportion of a vehicle's lifecycle CO_2 emissions occurring during the production phase. Consequently, vehicle manufacturers and suppliers must now prioritize optimizing the entire product lifecycle rather than focusing solely on the 'in-use phase.' This paradigm shift necessitates a comprehensive approach to product development that encompasses all stages of a vehicle's lifecycle. In this context, the circular economy and sustainable battery solutions have garnered significant attention from global authorities and regulatory bodies. A pivotal development in this area is the EU battery passport regulation, set to come into force in 2027. This regulation mandates new reporting requirements for all electric vehicles and industrial batteries larger than 2kWh, irrespective of the battery's origin. The regulation aims to enhance transparency and accountability in battery lifecycle management, thereby promoting sustainability. Digital battery passports represent a transformative innovation in the rapidly evolving landscape of sustainable energy. These passports are poised to revolutionize battery lifecycle management by providing detailed information on the battery's origin, composition, and performance throughout its lifecycle. However, the implementation and integration of battery passport solutions present several challenges, including data traceability, data integration and quality, and compliance with regulations. These challenges are particularly significant given the nascent stage of the market for battery passport solutions and the scarcity of reference projects. Addressing these challenges requires a holistic approach that combines robust platforms, specialized know-how, and comprehensive consulting and advisory services. This presentation will explore various options for applying the EU battery passport regulation and the legislative boundary conditions for batteries within the EU. It will also showcase best practice examples and strategies for CO_2 reduction in battery production and lifecycle management. The second part of the presentation will delve into a real-life application of battery passport definitions within a battery production environment, highlighting practical insights and lessons learned.

47 Digital product passport concept for an aluminum bike frame: A case study to enhance circularity and sustainability

Tom Kenntner[1], Nicola Obermeier[1], Emma Leonie Pittino[1], Klara Schilcher[1], Julius Ott[1], Katharina Berger[1,2]

[1]*University of Graz, Graz, Austria.*

[2]*Christian Doppler Laboratory for Sustainable Product Management enabling a Circular Economy, Graz, Austria*

Abstract

Cycling poses an active mobility mode that offer low-cost and low to zero emissions compared to other mobility modes. Respective bicycles, or rather bicycle frames often consist of aluminum, linking high energy consumption and environmental impacts to the respective life cycle. The transition to circular and sustainable value chains requires transparent data access across all lifecycle stages. In this context, Digital Product Passports (DPPs) offer a structured approach to improving sustainability and circularity by facilitating data-driven decision-making. DPPs in the bicycle industry are still under development, however, applying a DPP to bicycles has great potential to foster sustainability and circularity. This study proposes the first structured DPP framework for aluminum bicycle frames and use cases in the context of sustainable product management (SPM). The development of the DPP framework is based on a structured stakeholder mapping, a systematic literature review and a preliminary expert validation by conducting two expert interviews. The DPP concept comprises 62 data points organized into four categories: (1) bike frame specifications, (2) diagnostics and maintenance, (3) sustainability and circularity, and (4) value chain actors. These data points provide insights into material traceability, lifecycle impacts, and product repairability, supporting SPM. The concept also details the specific data requirements of the affected stakeholders, such as engineers, consumers, and recyclers. Furthermore, four use cases illustrating how stakeholders can leverage the DPP to enhance circularity and sustainability in bicycle production and disposal were derived. This study contributes in three ways. First, it introduces a DPP concept for aluminum bicycle frames to enhance value chain circularity and sustainability. Second, it introduces a concept that improves data transparency and facilitates data-driven decision-making, serving as a foundation for future DPP development. Third, the study provides actionable insights for stakeholders to support the adoption of DPPs to accelerate the transition to a circular economy

Afternoon Session 2.1: Innovative Rail Vehicle Design: Lightweight Structures, Efficiency, and Integrated Functions

16:00 - 17:30 Tuesday, 23rd September, 2025

Chair:
Hanno Bachler-Udier, AVL List GmbH

Location:
Weitzer, Room “Styria”

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5 Impact of normative loads and conventions on car body weight and structure for a rural rail vehicle

Christian Gomes Alves, Müller Thomas, Jens König

German Aerospace Center, Stuttgart, Germany

Abstract

Lightweight design in rail vehicles is crucial for enhancing energy efficiency, reducing operational costs, and lowering greenhouse gas emissions. This paper presents an overview of the key structural considerations and design principles involved in the early mechanical design of the car body of a small regional vehicle developed as part of the Horizon Europe Project “FutuRe”. The project aims to create a lightweight, two-axle rail vehicle for rural Europe, with a maximum weight of 32 tons. The design process employs a comprehensive methodical lightweight design approach, including topology optimizations to estimate and minimize the structural mass of the car body and gain insights into its optimal structural design. The results indicate that longitudinal loads for different load categories from EN 12663-1 have minimal impact on the car body’s structural weight. Furthermore, the location of heavy equipment like batteries has a negligible impact on the structural car body mass as well, featuring similar structural results. The findings suggest that normative boards should revaluate the necessity of distinct longitudinal loads for car body development.

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24 Resource efficient regional train facilitated by single-axle running gears

Rickard Persson, Prasidya Wikaranadhi, Sebastian Stichel

KTH Royal Institute of Technology, Stockholm, Sweden

Abstract

Regional railway lines with lower usage or part of secondary networks play a vital role in serving regions and as feeders for passenger and freight traffic for the main/core network. These railway lines need to be renewed to make them economically and environmentally sustainable and this is the aim of FutuRe – a project supported by the Europe’s Rail Joint Undertaking. Research is conducted in several areas, like traffic management, train positioning, automatic train control, wayside assets, multi-modal travelling, and

the vehicle itself, where the propulsion system and the running gear are key research areas. Low weight and cost are crucial aspects for a resource-efficient regional train. Running gears make up a significant part of the weight of a railway vehicle and use of single axle running gears instead of conventional two-axle bogies would reduce the weight and cost. Single axle running gears have been used for rail vehicles from the beginning. Most of the applications have been for freight service where performance has been less important than the acquisition cost. In FutuRe, it is proposed that single axle gears should be used for a two-axle regional train and that the shortcomings of such a simple design should be mitigated through low force active suspensions. Two types of active suspensions are proposed, an active vertical dynamic suspension to ensure good vibration comfort and an active wheelset steering to ensure good curving performance. The solutions are presented together with early simulation results. The impact on Key Performance Indicators used in FutuRe shows that the proposed vehicle will have lower energy consumption, generate less external noise and require less maintenance compared to the regional train offered by the market today.

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27 Comparison of integrated functions in a multifunctional sandwich composite rail car body

Péter Bondár[1,2], Per Wennhage[1,2], Malin Åkermo[1], Sebastian Stichel[1]

[1]*Department of Engineering Mechanics, KTH Royal Institute of Technology, Stockholm, Sweden.*

[2]*The Centre for ECO2 Vehicle Design, Stockholm, Sweden*

Abstract

The need for sustainable transportation and the shift from road to rail require innovative solutions to reduce service costs. Multifunctional sandwich-structured composites, which integrate multiple functions traditionally performed by separate materials in rail vehicle car bodies, offer potential benefits such as reduced material usage and weight savings. In addition to meeting structural requirements, these materials can also provide sound and heat insulation while fulfilling safety regulations. This study investigates the material selection process for sandwich composite face and core materials, focusing on the interdependencies between integrated functions. Materials are evaluated based on their mechanical, thermal, and acoustic properties, as well as compliance with safety standards. A multi-criteria decision analysis (MCDA) approach, combined with the Ashby method, is applied to systematically compare trade-offs between competing requirements, illustrating how prioritising one property affects overall performance. The findings provide a structured material selection framework for optimising multifunctional sandwich composites in rail applications, supporting the development of lighter, more cost-effective, and sustainable vehicle designs.

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29 Understanding Motor-Inverter Design Interactions in Rail Vehicles Using Network Theory and Sensitivity Analysis

Sai Kausik Abburu, Ciarán J. O'Reilly, Carlos Casanueva,

The Centre for ECO2 Vehicle Design, Stockholm, Sweden

Abstract

Vehicles are complex systems composed of multiple interdependent subsystems. A design change in one subsystem can lead to either beneficial or detrimental effects on others, making it essential to understand how design choices propagate through the system. This paper focuses on the traction chain in rail vehicles, specifically the interaction between two critical subsystems: the traction motor and the inverter. Since the inverter supplies the current and voltage required by the motor, changes in motor design can affect the inverter's thermal behaviour. We analyse this interaction to understand how motor design influences the temperature evolution of inverter power electronic components. To achieve this, we apply a framework that integrates network theory, structural equation modelling (SEM), and sensitivity analysis. First, analytical models of a three-phase induction motor and an inverter thermal model are developed. A reverse breadth-first search is used to identify all input parameters that influence the inverter temperature. Global sensitivity analysis (GSA) isolates the most influential inputs, enabling the construction of a reduced network graph. Then, SEM and local sensitivity analysis (LSA) are applied to quantify the relationship between motor design parameters and inverter temperature, yielding a coefficient that captures the strength of the dependency. This approach provides an alternative representation of the multidisciplinary interactions between subsystems. It also helps identify key change propagation paths, making it easier for designers to anticipate and manage the consequences of design changes. By reducing analytical complexity and clarifying subsystem interdependencies, the framework supports more efficient early-stage design, potentially reducing the number of iterations needed to reach a satisfactory solution.

Afternoon Session 2.2: Advancing Energy Efficiency and Sustainability in Mobility Systems

16:00 - 17:30 Tuesday, 23rd September, 2025

Chair:
Sophie Isaksson Hallstedt, Chalmers Tekniska Högskola

Location:
Weitzer, Room “Riverside”

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14 Optimizing energy consumption of regional trains through speed adjustment: a seasonal and regional perspective

Amir Torkiharchegani[1], Marcel Scharmach[2], Mats Alaküla[1], Rickard Persson[3], Libor Lochman[4], Christoffer Ahrling[5], Martin Tunér[5]

[1]Division of Industrial Electrical Engineering and Automation, LTH, Faculty of Engineering, Lund University, Lund, Sweden

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[4]Wabtec Corporation, Rome, Italy. [5]Department of Energy Sciences, Lund University, Lund, Sweden

Abstract

Efficient energy management is a key challenge for regional train services, especially when considering the seasonal variation in auxiliary energy demands such as heating, ventilation, and air conditioning (HVAC). This study explores how adjusting the maximum operational speed of regional trains can optimize energy consumption without exceeding design limits or necessitating larger battery sizes. By achieving a balance between train speed, available travel time, and seasonal auxiliary energy needs, the study proposes an approach to enhance sustainability and reduce operational costs. The research begins by modelling HVAC energy demands under different climatic conditions and train capacities. Using this model, energy consumption for a battery-powered regional train is simulated on two distinct routes: each with unique drive profile and timetables. The simulations are conducted using MATLAB, considering the impact of speed adjustments on both traction energy and auxiliary energy requirements. Results demonstrate the significant potential of speed adjustments to reduce total energy consumption. This approach ensures that battery sizes remain manageable while maintaining performance standards across different routes and timetables. Furthermore, the findings highlight the broader implications of speed adjustment on battery lifecycle, and CO_2 emissions. This research underscores the importance of precise speed adjustments in achieving optimal performance, cost-effectiveness, and sustainability in regional rail services.

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6 Assessing Climate Neutrality and Circularity Potentials - A LCA Case Study on City Buses

Gerfried Jungmeier[1], Jarod Kelly[2], Nikolas Hill[3] *and Partners in IEA EV Task 46*

[1]JOANNEUM RESEARCH, Graz, Austria

[2]ARGONNE, Chicago, USA. [3]Ricardo, London, United Kingdom

Abstract

Reaching climate neutrality by GHG reduction and circularity by closed material cycles is a societal challenge. They are addressed by the methodology of dynamic Life Cycle Assessment (LCA), where GHG emissions with its radiative forcing potential and material flows with its (non-)circular flows are calculated over the entire lifetime. In the Technology Program of the International Energy Agency experts from 20 countries cooperated in a case study for 100% climate neutral city buses to compare different propulsion systems in combination with Carbon Capture & Storage (CCS). An methodology was developed and tested in various applications. A product is “climate neutral“ and “circular“, if its whole life cycle - production, operation and end-of-life - uses only reused components, recycled material, renewable energy and makes no waste and no GHG emissions. The indicator for circularity is the CPO calculated in the dynamic LCA, which uses the material flows of the considered systems in its total lifetime including non-renewable energy. The Climate Neutrality Potential (CNP) is based on the cumulated GHG emissions in the Impact Assessment of dynamic LCA. The total top-of-atmosphere radiative forcing potential based of the GHG emissions over lifetime is calculated in W per m². Key findings are 1) Climate Neutrality Potential & Circularity Potential are additional environmental impacts in dynamic LCA not yet covered in existing Impact Categories. 2) Only systems using renewable energy have the potential towards Climate Neutrality and Circularity. 3) Only in combination with CCS all buses might be “100% climate neutral”. 4) The Circularity Potential of electric, hydrogen and e-diesel buses are quite similar (48 - 57%), for diesel it is very low (3%). 5) The diesel bus has the highest environmental impacts. 6) For 100% Climate Neutrality the electric bus with CCS needs the same amount of additional renewable energy than the diesel bus with CCS.

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41 A techno-economic assessment of battery-electric and fuel cell electric powertrain systems for the transformation of the heavy-duty transport

Tobias Otto[1], Thomas Grube[1], Jochen Linßen[1], Detlef Stolten[1,2]

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Abstract

The transformation of the energy system also provides the transport sector with the opportunity to reduce primary energy use, increase overall efficiency, and reduce greenhouse gas emissions. While the light-duty vehicle fleet is increasingly being electrified by battery electric powertrains, challenges of road-based freight and passenger transportation in moving large masses over long distances remain due to high weights and costs of batteries. In this regard, hydrogen by green electricity or e-fuels can provide gravimetric and economic advantages under certain operating conditions. This requires an individual, thorough decision-making process for determining the most economically optimal technology. A comparative assessment of the techno-economic performance of respective powertrains is necessary to identify preferrable

combinations of powertrain technology and vehicle application, exhibited in the context of the provision of renewable electricity and hydrogen by the energy system. This investigation presents the results of a bottom-up, simulation-based analysis of zero emission vehicle powertrains integrating detailed technical and user cost analyses methods incorporated in an overall energy system scenario. The related approach is suitable for a broad variety of vehicle segments and applications scenarios. To perform energy demand calculations, a longitudinal dynamic vehicle model was developed that incorporates user-specific velocity profiles also considering topographical information. A comparative evaluation of different vehicle classes and specific scenarios based on energy demand, total cost of ownership as well as infrastructure requirements is derived from the cost analysis. It builds on a bottom-up component cost analysis which integrates the learning curve approach based on cumulative production volumes. Appropriate vehicle powertrain and application combinations are identified from the results of this study. The economic efficiency is highly dependent on vehicle energy costs as well as the associated availability of the required energy demand. These findings provide valuable insights for policymakers and industry stakeholders, supporting strategic decisions for sustainable road transport.

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12 Environmental and socio-economic potentials of automated cars on the European passenger car fleet

Thu Trang Nguyen, Mario Hirz

Graz University of Technology, Graz, Austria

Abstract

Automated vehicles (AVs) are considered as one of the most significant disruptive technologies in mobility systems in the coming years. AVs have the potential to create impacts at different levels, from single-vehicle level (i.e., added weight and energy demand from sensing and computing components) to the entire fleet (e.g., reductions of traffic congestion, fewer traffic accidents, and shorter delays). Understanding how AVs will affect mobility systems and user behavior from both environmental and socio-economic perspectives is an important topic for AV development and their penetration into the fleet. Focusing on passenger cars, this paper aims to investigate a wide range of potential impacts, i.e., technical, socio-economic, and environmental, caused by automated cars on the European passenger car fleet. First, potential environmental impacts will be discussed in view of reduction of emissions due to improved traffic, but also in view of increased energy consumption and changed user behaviors. Second, AV impacts on vehicle costs, including fixed, variable, social, and environmental costs, will be assessed. Next, fleet characteristics, such as the number of vehicles-in-use and penetration rate, will be combined with AV-related vehicle impacts to quantify AV impacts on the fleet. Potential impacts of AVs are analyzed across several scenarios that differ in terms of penetration rates, as well as in additional fuel and energy consumption resulting from AV operation (labeled Average, High saving, and No saving). The results indicate that fleet scenarios with lower total fleet emissions tend to have lower total fleet costs. In addition, supportive policies and business models that enable AVs to achieve their maximum emission saving potential are key to a sustainable fleet.

Day 2

Morning Session 1.1: Data-driven Circular and Sustainable Vehicle Management

10:00 - 12:00 Wednesday, 24th September, 2025

Chair:
Josef-Peter Schöggl, University of Graz

Location:
Weitzer, Room “Styria”

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22 Hybrid Modeling for Second-Life Battery Optimization in Light Electric Vehicles

Andrés Bernabeu-Santisteban[1], Alejandro Clemente[1,2], Bernhard C. Geiger[3,4], Franz M. Rohrhofer[3], Francisco Díaz-González[2], LLuís Trilla[1]

[1]Power Systems, Catalonia Institute for Energy Research, Barcelona, Spain

[2]Polytechnic University of Catalonia, Barcelona, Spain

[3]Know Center Research GmbH, Graz, Austria

[4]Signal Processing and Speech Communication Laboratory, Graz University of Technology, Graz, Austria

Abstract

The repurposing of second-life lithium-ion batteries (LIBs) offers a sustainable solution for less demanding applications, such as light electric vehicles (LEVs) or stationary storage. However, limited information on their usage history and internal condition hinders their effective reuse. This paper presents a hybrid modelling (HM) approach that combines a data-driven model (DDM) with a physics-based model (PBM) to assess battery health and predict future performance. The DDM estimates, from a simple charge test, three key parameters: state of health, full equivalent cycles, and active material volume fractions. These are then used to initialize the PBM, which simulates degradation and estimates remaining useful life under LEV application profiles. Trained on experimental data from NMC811 cells, the HM demonstrates strong potential as a practical tool for second-life battery evaluation for different types of cells, integrating adaptability and physical accuracy in a single framework.

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28 Optimizing energy use in electric vehicles: A comparative studyof optimization methods

Wilmer Liljenström, Malte Rothhämel

KTH, Stockholm, Sweden

Abstract

Electric and hybrid passenger vehicles offer the ability to recover braking energy and optimize power distribution, enabling significant improvements in efficiency compared to conventional vehicles. In this study, we quantify and compare the energy-saving potential of three optimization methods—mixed-integer linear programming (MILP), nonlinear programming (NLP), and dynamic programming (DP)—for a battery-electric vehicle following the Urban Dynamometer Driving Schedule (UDDS). A simplified longitudinal EV model with aerodynamic, rolling, and gravitational resistances is used to simulate vehicle dynamics, battery charging/discharging, and regenerative braking. The reference case enforces exact tracking of the UDDS speed profile, including late, hard braking at stops. Over a receding horizon of five seconds, MILP linearizes resistive forces and solves a linear program (≈13 ms per step), while NLP retains full nonlinear dynamics with a quadratic speed-deviation penalty (≈2 ms per step). DP serves as an offline global benchmark across a discretized state-of-charge grid. Results show that, relative to the baseline, NLP achieves the largest net-energy reduction (23.2 %), followed by MILP (19.0 %) and DP (13.6 %). NLP's ability to model exact aerodynamic drag and smoothly coast into stops yields the highest savings but requires more computational effort. MILP offers a compromise between efficiency and real-time feasibility on automotive ECUs, although its hard speed bounds induce oscillatory speed errors. DP, while globally optimal under exact speed tracking, is best suited as an offline reference. These findings suggest that hybrid approaches—such as DP-trained lookup tables or variable-efficiency NLP surrogates—could approach global optimality while meeting real-time constraints. Future work will validate these methods on additional driving cycles and incorporate variable motor/regenerative efficiency maps to better align with real-world performance.

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38 From customer usage to a sustainable product offering through digitalization

Neda Abdolrashidi, Fredrik Öijer

Volvo Group Truck Technology, Gothenburg, Sweden

Abstract

To develop sustainable vehicles understanding their intended usage is crucial. This knowledge allows us to translate usage patterns into specific requirements, enabling the design of optimal transport solutions. To gain a holistic understanding of the real usage of our trucks, it is essential to provide insights into both vehicle performance and the environment in which they are operated. Logged vehicle data provides a valuable source for understanding customer usage patterns. This data can be clustered into groups with similar usage profiles, and these patterns can then be translated into the requirements. To apply clustering, real-time tracking and data collection from vehicles are necessary. In this work, telematics technology has been utilized as a digitalization tool, enabling seamless transmission, storage, and reception of daily logged vehicle data. The data flow serves as the foundation for conducting a variety of analytics using advanced AI techniques. Amongst the collected data, a set of about fifteen parameters related to the vehicle usage and operating environment have been selected as the input to this study. Clustering, which is one of the popular AI techniques, has been applied to group data points by implementing a multidimensional algorithm enabling us to handle daily data readings for several parameters over one year and for about two million

trucks driving over the globe. In the next step as a verification of the identified clusters in addition to statistical methods, a comparison of the output with information collected in interviews with customers in different transport applications around the world has been performed. Combining the clusters and customer studies with vehicle domain knowledge resulted in identifying the Transport Application Descriptions (TAD). This study also shows how the proposed method can be applied to assess various transport solutions for different customer applications, with the aim of identifying the optimal transport solutions.

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49 **Social life cycle assessment of battery electric vehicle following ISO 14075 standard**

Davis Jose, Marzia Traverso

Institute of Sustainability in Civil Engineering, RWTH Aachen, Aachen, Germany

Abstract

Beginning with a meticulous examination of the social ramifications inherent in Battery Electric Vehicle (BEV) lifecycles, this study delves into the complexities of sustainable mobility. Through a comprehensive Social Life Cycle Assessment (S-LCA), enriched by a detailed case study of a German-manufactured Sport Utility Vehicle (SUV) and an extensive review of existing literature, the research illuminates the social footprint from resource extraction to end-of-life recycling. The study meticulously assesses social impacts across various stakeholder categories, including Workers, Local Communities, Consumers, and Society, pinpointing critical social sustainability issues. Utilizing OpenLCA software and the Product Social Impact Life Cycle Assessment (PSILCA) database, the research provides a practical guide for both academia and practitioners, detailing each step of the S-LCA process. Key findings reveal significant threats, notably forced labor, hazardous working conditions, gender wage disparities, and the alarming prevalence of child labor in resource-extractive industries, particularly in regions like the Democratic Republic of Congo, Russia, Poland, and Chile. During the usage phase, governance-related challenges such as corruption, bribery, and anti-competitive practices are identified, primarily associated with electricity generation and material supply chains, especially concerning Germany's trade dependencies with neighbouring countries. While the end-of-life and distribution stages exhibit relatively lower overall social impacts, they still present specific concerns, such as land use in recycling. The interpretation phase highlights increased medium-risk hours in scenarios involving material inputs from diverse countries and high-intensity usage patterns like high speeds and full charging cycles. The research underscores the urgent need for global, coordinated efforts to solve social risks within BEV supply chains. This study contributes to the ongoing discourse on sustainable mobility, pinpointing crucial areas for improvement to mitigate divestment impacts, foster a fairer supply chain, and cultivate a more socially sustainable automotive industry, acknowledging the current absence of global sustainability standards for BEVs.

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23 Data-driven prediction of the viability of remanufacturing for heavy-duty vehicle components

Johan Larsson[1,2], Michael Lieder[4] ,Josef-Peter Schöggl[3], Ciarán J. O'Reilly[1,2]

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[2]ECO2 Center for Vehicle Design, Stockholm, Sweden.

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[4]Scania, Södertälje, Sweden

Abstract

The production of a heavy-duty road vehicle is a major contributor to the overall financial cost and environmental impact of the vehicle. In recent times, closing the material loops using circular practices has emerged as a promising approach to reduce the environmental impact of the vehicle production. The most common circular practice is material recycling, but this is a low-value process, as any embodied value in the product apart from the material refinement is lost and, even then, the recycling process might be cumbersome if the product is composed of multiple materials that cannot be easily separated. An upcoming and promising approach to circularity is remanufacturing where a product is disassembled and the constituent components are cleaned and inspected. The components which pass the inspection are then reused in new products. This preserves the value in the reused products and not only reduces the consumption of raw materials, but also manufacturing effort. In order for the remanufacturing process to be worthwhile, some conditions need to be satisfied. Firstly, the product needs to be valuable enough for the remanufacturing effort to make economic sense. Secondly, the state of a product that is returned from a customer must be able to be ascertained with a certain degree of confidence in a quick manner. One way to evaluate the state of a returned product is by using the historical usage data of the vehicle it comes from. The goal of the work presented here is to study the feasibility of remanufacturing for different heavy-duty road vehicle components based on the economical benefits as well as the availability of data for the component in question, as well as identifying the relevant data for evaluating the remanufacturability of the component in question.

Morning Session 1.2: Innovations in Sustainable Transport

10:00 - 12:00 Wednesday, 24th September, 2025

Chair:
Jenny Jerrelind, KTH Royal Institute of Technology

Location:
Weitzer, Room “Riverside”

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15 Enhancing Energy Efficiency and Environmental Sustainability through Regional Battery-Powered Train Energy Transfer Systems

Amir Torkiharchegani[1], Mats Alaküla[1], Christoffer Ahrling[2], Martin Tunér[2], Libor Lochman[3], Marcel Scharmach[4], Rickard Persson[5]

[1]Division of Industrial Electrical Engineering and Automation, LTH, Faculty of Engineering, Lund University, Lund, Sweden

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[3]Wabtec Corporation, Rome, Italy

[4]Institute of Vehicle Concepts, German Aerospace Center, Stuttgart, Germany

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Abstract

The increasing integration of renewable energy sources and electrified transportation systems calls for innovative energy management strategies, especially in regions where grid infrastructure is limited or economically unviable. This study explores the concept of using regional battery-powered trains not only as sustainable transport modes but also as dynamic energy carriers, similar to Vehicle-to-Grid (V2G) and Vehicle-to-Vehicle (V2V) systems. Battery-powered trains can be charged at stations supplied by renewable sources during off-peak hours, then transport stored energy to remote areas with weak grid access. This energy may support local microgrids, station operations, or charge other vehicles. Such systems are particularly valuable where full rail electrification is infeasible, offering a decentralized energy distribution solution. Topography enhances this concept. Trains ascending steep inclines require more energy, while those descending consume less. Coordinating energy transfer between trains on opposite gradients can reduce battery size requirements and improve overall efficiency. This reduces reliance on costly grid expansion and improves battery utilization. The approach also helps stabilize the grid by aligning charging with low-demand periods, enabling better use of renewable energy. In semi-electrified routes, trains with surplus energy could discharge to others or the grid, enhancing energy flexibility. The economic and environmental benefits are notable: reduced grid investment, lower greenhouse gas emissions, and smaller battery needs due to smarter sizing. This concept positions trains as mobile energy assets, contributing to more sustainable energy and transport systems

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36 Automated train preparation and operation: A target costing based approach for a regional line in Germany

Alessa Isberner[1], Florian Brinkmann[2], Justin Adam[3], Raphael Hofstädter[4]

[1]*German Aerospace Center (DLR), Berlin, Germany*

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[3]*TU Berlin, Berlin, Germany*

[4]*ALSTOM Transport Deutschland GmbH, Salzgitter, Germany*

Abstract

Working towards a more sustainable transportation systems the attractiveness of the railway as an environmental mode of transport has to be strengthened. The project ARTE aims to increase the efficiency of regional railway transport through new technical solutions in the field of automation, especially refitting of existing trains with automation and using as-is infrastructure. Highly automated railway operation scenarios where significantly less activities by operating personnel is required on the train are outlined in the project. One of them is that the lack of operating personnel such as train drivers can lead to cancelation and delays in service and further to dissatisfaction with the railway transport from a customer perspective as well as penalty payments and an unprofitable operation for the operator. Also, automation promises higher frequency of trains during the day and reliable train services at night by presumably lower running costs and better usage of infrastructure. However, in order for new technical solutions to assert themselves in the market and not remain a theoretical research objective the cost efficiency has to be proven. To correspond to this the operational as well as the economic potential of the automation solution has been analysed. To ensure that the business case is at least on the same level as the status quo a target cost analysis based approach has been performed to estimate the minimal cost for the envisaged automation solution from an operator's point of view. The methodological procedure that was developed can be used to determine the target costs for automation technology for all operating areas if an overview on the process elements and their time shares of the total working shift are available. This paper presents an approach for evaluating the cost-efficient implementation of new technology to increase efficiency through the automation of railway operations.

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18 Advancing the quantification of tyre wear and particulate emissions on an outer drum test bed: challenges and laboratory solutions

Ludwig Schubert[1,2], Maria Alejandra Arias Torres[1], Daniel Heuberger[1], Matthias Ehrenhuber[1], Cornelia Lex[1]

[1]*University of Technology Graz - Insitute of Automotive Engineering, Graz, Austria*

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Abstract

Tyre wear is a significant source of environmental microplastics and airborne particles smaller than 10 µm, posing health risks by reaching the lungs and other organs. Precise quantification and regulatory measures are essential. This study aims to develop a reliable method to quantify both tyre wear and tyre wear particles simultaneously under realistic laboratory conditions. Achieving realistic tyre wear rates on an outer drum test bench requires degumming methods, such as talc powder, to prevent the tyre from sticking to the drum

surface. However, this complicates accurate measurement of tyre wear particles due to additional particulate emissions from the talc powder. The test setup at TU Graz includes a flow-optimised enclosure that minimises background particle entry. This configuration, coupled with a GTR-24-compliant sampling system, facilitates precise particle measurements. Key instruments include two AVL Particle Counters for particle number concentration, two Particle Mass Samplers for particulate mass, and an ELPI+ (Electrical Low Pressure Impactor) for size distribution analysis. Results show that minimising background emissions is crucial for accurate tyre particle analysis. Using talc powder as a degumming method increased tyre wear rates by a factor of 10 compared to measurements without it. However, talc powder added complexity to the measurements by significantly contributing to particulate mass. Size distribution analysis revealed clear distinctions between talc and tyre wear particles, with talc contributing predominantly to coarser particle fractions (PM10) compared to finer tyre wear particles (PM2.5). Despite these advances, distinguishing between talc and tyre wear particles remains challenging. Avoiding degumming methods yields unrealistically low tyre wear rates, highlighting the need for alternative methods that achieve realistic wear rates without additional particle sources. This research underscores the importance of refining measurement techniques for tyre wear and tyre wear particles to assess environmental and health impacts and inform regulatory frameworks.

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21 Overcoming institutional barriers in socio-technical transitions: The case of ship electrification project

Anastasia Tsvetkova[1], Magnus Gustafsson[1,2], Henry Schwartz[1], Magnus Hellström[1,3]

[1]Åbo Akademi University, Turku, Finland

[2]PBI Research Institute, Turku, Finland

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Abstract

This study explores the transition to all-electric RoPax (Roll-on and Passenger) ferry transportation, focusing on the institutional structures within the current business ecosystem that hinder this shift. RoPax shipping, which combines wheeled cargo transport with passenger services, significantly contributes to greenhouse gas emissions due to its reliance on internal combustion engines. Although recent regulations from the International Maritime Organization (IMO) and the European Union promote alternative fuels, the adoption of electric vessels remains limited. Drawing on empirical data from a two-year project developing an electric RoPax vessel for a Baltic Sea route, this research involves collaboration with a shipyard, a ship operator, and a local energy company. Utilizing a framework that integrates the Multi-Level Perspective (MLP) on socio-technical transitions, institutional theory, and business ecosystem analysis, the study reveals that the stability of the socio-technical regime is maintained through entrenched business ecosystem structures. Findings indicate that existing value creation configurations obstruct the transition to electric vessels, emphasizing that business ecosystems reflect embedded institutional arrangements. The proposed framework illustrates how regime stability is shaped by interdependent actor roles and investment sequences, highlighting the need for structural reconfiguration to facilitate the integration of niche innovations into the dominant regime. The study concludes that successful transitions require not only technological advancements but also a comprehensive restructuring of ecosystem roles and responsibilities to overcome barriers and enable sustainable practices in the maritime industry.

Afternoon Session 1.1: Bridging Sustainability and Design I

14:00 - 15:30 Wednesday, 24th September, 2025

Chair:
Ciarán J. O'Reilly, KTH Royal Institute of Technology

Location:
Weitzer, Room "Styria"

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35 User Roles for Circular Product Development Software

Marie Schwahn[1], Thomas Potinecke[2], Lukas Block[2], Sebastian Stegmüller[2], Ann-Kathrin Briem[3], Martin Musser[4]

[1]University of Stuttgart, Stuttgart, Germany

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[3]Fraunhofer IBP, Stuttgart, Germany

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Abstract

The global scarcity of resources increases the need to develop more sustainable and circular products. Circular economy principles like repair, remanufacture or reuse must be considered early in the development process. The development of such products is complex due to interdependent criteria and the systemic nature of automotive products. To mitigate this complexity, model-based software tools can be used to illustrate relevant dependencies between different criteria and evaluate product designs in terms of circular economy and sustainability. Before developing such software, it is crucial to clearly define the user groups and roles that will interact with the system. This ensures the protection of sensitive data, enhances user experience, and aligns workflows with the specific needs and goals of various stakeholders — particularly developers. This paper focuses on defining roles for a model-based software tool for circular and sustainable product development, currently being developed within the 'Cyclometric' research project. Criteria for these roles were identified and a suitable methodology for role definition was developed, followed by a formal evaluation of the developed roles.

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37 Mind the gap: An in-depth analysis of methodological frameworks for integrating environmental criteria in MEAT-based public tenders for metro rolling stock platforms

Kevin Lukas Kulle

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Abstract

Climate change as a universal challenge has led to stringent regulations across industries, including the rail sector, which seeks to maintain its status as the most environmentally friendly means of transport while also facing intense global competition in the market. To address these issues, the European Union and several railway associations advocate for MEAT-based tenders, thereby emphasising the evaluation of multiple award criteria in public procurement. A key criterion in this regard is the environmental performance of rolling stock over their entire life cycle. The focus of the present research study was to explore the integration of environmental performance factors as award criteria for public tenders in the metro rolling stock sector. It investigates metro-specific requirements, technical specifications, and economic evaluation models, selecting and adapting an environmental assessment tool to enable LCA in early product development phases. The developed Fast Track methodology is applied to various scenarios and subjected to parameter variation for validation. The findings demonstrate that solid standards, guidelines, and directives are in place to frame sustainability in tender evaluations. Moreover, the Fast Track LCA approach proves to be effective for high-level assessments in the initial design phases. By incorporating hotspot analysis, the developed model supports eco-friendly design decisions, enabling the comparison of environmental indicators in tender evaluations and promoting sustainable procurement practices in the metro sector.

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33 Estimating potentials and trade-offs of material utilization in automotive applications

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Abstract

Within the extended abstract, the potential of implementing new materials into crash-management-systems (CMS) of passenger vehicles is discussed. The global warming potential (GWP) of a CMS containing wood-based material compositions is calculated under different shared-socio-economic pathway scenarios (SSP scenarios). With decreasing rigidity of the SSP scenario, the potential to mitigate GWP of CMS by substituting wood-based materials decreases. In further steps a system dynamics model should be used to estimate trade-offs between different sectors, if there is a shift of wood as a material to the automotive sector.

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32 Design-to-CO_2 with OPED: AI-Powered design optimisation of electric powertrains

Dominik Lechleitner, Martin Hofstetter

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Abstract

Electric vehicles (EVs) do not produce local greenhouse gas (GHG) emissions during operation. However, their indirect emissions categorized as scope 3 according to the GHG protocol still result in a relevant carbon footprint and reporting of those emissions is mandatory. Accordingly, it is important to follow a design-to-CO2 approach when developing new EVs: GHG emissions are already considered in the early-stage design of EVs and engineers aim at minimising the emissions. In the present work, this is achieved by considering scope 3 emissions in a design optimisation software for electric axle drives (e-drives), which is called OPED (Optimisation of Electric Drives). OPED utilises AI-methods to generate best possible e-drive design solutions for engineers and provide them with a solid basis for decision-making. That way, the emissions of newly developed e-drives can be directly minimised alongside the optimisation of other design objectives, e.g., production cost, energy efficiency and package integration. Furthermore, different supply chains are considered and characterised by their specific costs and GHG emissions. The supply chains include standard as well as low-carbon-footprint materials and different supply routes. As a result, a Pareto front of optimal design solutions for specified e-drive requirements is obtained. The method is applied to a case study, which involves the optimisation of an e-drive for a passenger car. The obtained Pareto front and found trade-offs between scope 3 emissions, cost and energy efficiency are discussed, and a promising design solution from the Pareto front is selected to guide subsequent development.

Afternoon Session 1.2: Societal perspective in decarbonized transport solutions

14:00 - 15:30 Wednesday, 24th September, 2025

Chair:
Katharina Berger, University of Graz

Location:
Weitzer, Room “Riverside”

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26 Social consequences of replacing steel or aluminium in automotive applications

Claudia Mair-Bauernfeind, Theresa Boiger, Raphael Asada, Tobias Stern

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Abstract

Wood-based materials offer a promising lightweight alternative to conventional materials like steel or aluminium to reduce fuel consumption and thus the environmental impacts of vehicles. So far, research has been carried out to investigate the environmental impacts using alternative lightweight materials as an eco-design measure, though little is known about the potential social consequences. Consequences differ from impacts in that they not only examine the effects of a change within the product system itself but apply broader system boundaries to account for indirect and market-level effects (e.g., how the allocation of raw materials across industries in a region is affected). The aim of this study is to analyse the social consequences of using wood for automotive applications including potential side-effects on other forest-based industries in Austria. The social consequences of replacing conventional materials with wood in the Austrian automotive industry were analysed by implementing social indicators (e.g., occupational injuries, women in managerial positions) in the system dynamics model WOODSIM. The WOODSIM model depicts the Austrian wood utilization system and allows to simulate direct and indirect effects on the social performance resulting from shifts in wood supply across the industries of the forest-based sector. To illustrate the variability of effects depending on the specific application, two wood-based innovations were investigated: a wood-based side impact beam (SIB) for passenger cars replacing a steel-based SIB and a wood-hybrid battery compartment for battery electric vehicles (WBC) replacing aluminium and steel. In addition, these two innovations were compared to wood-based innovations in other sectors, namely in the construction and textile sector. Modelling the system dynamics of social consequences showed that steel is connected with higher risks regarding fatal occupational injuries than aluminium, resulting in less social consequences for the WBC. The high-risk countries for this indicator are especially the Ukraine, the Russian Federation and Chile. An improvement in the social performance can be thus achieved by designing the value chain in a way that only suppliers from low-risk countries are chosen. Comparing innovations of different industries shows that the automotive industry has the potential to result in bigger improvements than the construction or textile industry. This is mainly due to the transition of value chains from globalized to primarily regional ones. Hardly any effects can be observed if the replaced materials are largely sourced from Austria or neighbouring countries. Given the limited availability of wood, and assuming a consistently sufficient demand to clear the wood market, significant indirect effects on other wood-processing industries were observed. These findings can be used to identify optimization potentials in the Austrian wood utilization system in terms of its social performance. However, some of the results may be biased due to the poor data situation for the indicator of non-fatal occupational accidents. This work offers a first attempt

to model the social consequences of an innovation with system dynamics modelling which is essential to not overestimate positive effects when analysing consequences.

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34 Guiding the research on bio-based Supercapacitors towards a socially viable value chain development

Hanna Sofia Leiter[1,2], Daniela Groiss-Fuertner[1,2], Franziska Hesser[1,2], Treesa Chinju Charamkulath Vincent[2]

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Abstract

The transition to sustainable and resource-efficient vehicles is crucial for addressing social conditions and advancing electromobility. Conventional batteries using materials like lithium and cobalt are linked to significant social issues, prompting research into alternatives that avoid those issues. This study evaluates a bio-based supercapacitor under development in the EU project EMPHASIS through a Social Life Cycle Assessment (SLCA), aiming to enhance the social sustainability of electromobility. Supercapacitors offer advantages over batteries, including high power density, rapid charge-discharge cycles, and long operational life. The bio-based supercapacitor utilizes renewable resources for electrodes and bio-electrolytes, avoiding critical raw materials and toxic substances. These innovations promise reduced social impacts compared to conventional energy storage systems. Conducting SLCA during product development faces challenges like uncertain value chains and limited data availability. However, early social sustainability assessments are essential for creating sustainable products. Social risk mapping through expert workshops and secondary data highlights potential impacts across the supercapacitor's hypothetical global value chain. Resource extraction and end-of-life phases are identified as having the highest social implications, particularly for workers. The study underscores the potential of bio-based supercapacitors to significantly improve the social sustainability of electromobility. By leveraging renewable resources and fair manufacturing practices, they can reduce social risks while contributing to broader goals of equity and sustainable development. These findings provide valuable insights for stakeholders in the automotive and energy sectors, emphasizing the importance of integrating social innovation into next-generation supercapacitor development.

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42 Exploring the acceptance of shared follow-me delivery robots: An extended UTAUT2 approach

Viktoria Schett, Nina Hampl

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Abstract

This study explores the acceptance of shared delivery robots with follow-me function (SDR follow) within urban logistics, utilizing an extended version of the Unified Theory of Acceptance and Use of Technology 2 (UTAUT2) as its foundational framework. The research focuses on a specific use case in which SDR follow can be borrowed by users for short-distance transport of goods, groceries, or personal belongings.

Through qualitative focus group discussions with both non-experts (n=22) and experts (n=11) in urban goods transportation, the study proposes a set of factors that appear to be relevant for acceptance, including product attributes, facilitating conditions, performance expectancy, effort expectancy, perceived risk, service availability, perceived reliability, hedonic motivation and price value. The findings suggest that acceptance is shaped by a complex interplay of these exogenous and endogenous constructs, indicating the need for adaptations of the UTAUT2 model to address the unique characteristics of SDR follow.

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52 Discrete choice analysis of travel behaviour in Austria

Saumya Sadhu

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Abstract

The transport sector significantly contributes to environmental impacts, making its decarbonisation essential for meeting Europe's 1.5°C climate goal. This requires both technological improvements and shifts in travel behaviour. To support the latter, understanding current determinants of mode choice is crucial. This study uses a nested logit model calibrated with data from Austria's national mobility survey Österreich Unterwegs to examine how socio-demographic and infrastructure-related factors influence the likelihood of choosing public transport, cycling, or walking over car use. Results show that proximity to public transport and household income are key predictors. The findings also underscore car dependency in rural areas and reveal the inelasticity of car use with respect to travel time, suggesting strong behavioural lock-in.

Afternoon Session 2: Bridging Sustainability and Design II

16:00 - 17:30 Wednesday, 24th September, 2025

Chair:
Hanno Bachler-Udier, AVL List GmbH

Location:
Weitzer, Room “Styria”

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43 Leveraging driving simulator advances in early phase vehicle development - Partitioning of vehicle states for enhanced motion feedback

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Abstract

Driving simulators are increasingly adopted in early-phase vehicle development to reduce reliance on physical prototypes and enable faster, more iterative design cycles. This contributes directly to resource-efficient vehicle development by minimizing material use, shortening development time, and enabling early stage evaluations aligned with sustainability objectives. However, current simulator use is constrained by the limited realism of motion cueing algorithms (MCAs), particularly when filtering low frequency vehicle motions to stay within the physical workspace of simulators. This work proposes a novel motion cueing strategy based on partitioning global vehicle states into terrain-induced and vehicle-induced components. By preserving perceptually critical motion, such as pitch and roll motion relative to the local ground, while filtering global motion components, the method shows promising results for improving motion cueing fidelity. Two partitioning approaches are presented: a velocity-based method for pitch and a generalized terrain estimation method using tyre contact points. Results from simulations involving a slope and braking manoeuvre, and lateral road feature with turning manoeuvre demonstrate potential 1:1 retention of of vehicle and driver induced motion, while still filtering out ground induced motion, enhancing driver perception and subjective assessment fidelity. By enabling more accurate and representative simulator experiences without the need for physical prototypes, the proposed method supports early-phase, simulation driven validation of new vehicle concepts. This enhances the feasibility of virtual-first development strategies and accelerates the iteration of sustainability-oriented designs. Ultimately, the improved fidelity of motion cueing expands the role of simulators from supplementary tools to central assets in the resource-efficient vehicle development process. Future work will focus on real-time implementation and broader applicability across dynamic testing scenarios.

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20 Towards an approach to road cargo system-of-systems modelling

Per-Olof H. Sturesson, Ciarán J. O'Reilly

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Abstract

The transition from internal combustion engines to electric propulsion for road-cargo systems is on-going and faces multiple challenges for the involved actors and affected stakeholders. The product development of, for example, future battery electric heavy trucks for long distance hauling requires new perspectives on concept evaluation and selection due to high data uncertainty. These new perspectives are needed to satisfy the business objectives of both OEMs and transport providers, while also fulfilling an overall set of requirements, including environment-related ones. From a society point of view, public investments in electric power generation and distribution grids will be needed as use of electric energy will increase. These public investments need to be balanced and prioritized with other expenses. The investments in new technology in terms of battery electric haulers made by the transport providers need to be profitable and competitive with respect to utilization rate and cargo transport efficiency. The time duration of the mentioned activities is significantly different, which adds more complexity. The complexity of the road cargo system as a whole can be modelled as a system-of-systems, as the constituent systems like truck, transport and energy providers as well as energy and road infrastructure are independent managerially and/or operationally systems themselves. This paper describes the state and outlook of the conceptual modelling of key components in a general road cargo system of systems framework.

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45 Optimizing the configuration of a double-decker sleeping car from Germany to the Mediterranean – squaring the circle

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Abstract

The revitalization of night train services aims to offer a sustainable alternative to air travel on routes between 500 and 2000 km. However, high operating costs make ticket prices uncompetitive compared to low-cost airlines and high-speed day trains, resulting in the discontinuation of several services in Europe over the past 15 years. Challenges persist, including limited passenger capacity, large space requirements per passenger, and lack of seat turnover. Furthermore, the constraints of the G1 gauge limit international services, putting night trains in central Europe at a disadvantage compared to the American Superliner or the Finnish VR Ny, as well as other modes of transportation. This paper explores early-stage design strategies to improve the economic viability and efficiency of double-decker sleeping cars. Findings from Project “AliSa” identify critical design trade-offs and technical constraints. Desk research and CAD analyses reveal that accommodating two double cabins on both the upper and lower decks within the G1-profile is not feasible, as seen with the Superliner model. One alternative is to emphasize reclining armchair seating, which is less affected by height restrictions and offers greater flexibility. Norske tog’s survey indicates positive passenger attitudes towards this option, particularly when paired with private cabins to enhance privacy. Additionally, shorter but wider carriages improve spatial efficiency and comfort. A novel

configuration is proposed to maximize capacity while adapting to demand variations. Some armchairs are reserved for the entire journey, while others allow seat turnover. This setup incorporates adaptive lighting and modular partitions to balance privacy with occupancy efficiency. A linear programming simulation using demand scenarios and different ticket prices optimizes the upper deck configuration, combining two-person cabins, overnight armchairs, and turnover armchairs. Results indicate that turnover armchairs are more profitable in high-demand scenarios, while night armchairs gain relevance in lower-demand situations

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10 Sustainable Product Development Framework: Early-Stage Integration from Components to Product Sustainability – Speed Pedelec Case Study

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Abstract

Integrating sustainability considerations into the early stages of the Product Development Process (PDP) is essential for designing environmentally, economically, and socially responsible products. This paper presents a structured and scalable methodology for sustainable product development, applied to the case of a speed-pedelec. The proposed framework introduces intermediate variables to bridge the gap between component-level design variables and product-level indicators. Moreover, a two-stage process for identifying Key Design Variables is also developed. The methodology is designed to integrate seamlessly into existing PDPs through standard evaluation gates and supports iterative refinement as more data becomes available. A case study illustrates the practical application of the framework, with the goal of extending its range. The analysis includes a repairability assessment based on a reduced-order Bill of Materials, validated against full-product calculations. Results not only demonstrate acceptable improvement in range and efficiency, but also a measurable improvement in repairability, confirming the effectiveness of the proposed early-stage methodology. The framework is adaptable to various product domains and supports companies in making informed trade-offs between sustainability, performance, and cost from the earliest stages of design.