Conference on Technology Towards Zero Waste and Zero Carbon (TEC2ZERO)

Report of Contributions

Contribution ID: **3** Type: **Abstract TEC2ZERO**

Breaking the Mold: Unconventional Strategies for Sustainable Li-Ion Battery Recovery

As the demand for lithium-ion batteries (LIBs) surges due to the rise of electromobility and renewable energy storage, conventional recycling methods struggle to keep pace with sustainability goals. Current industrial processes rely heavily on energy-intensive and chemically aggressive techniques, raising concerns about environmental impact and scalability. This presentation explores innovative and unconventional approaches to LIB recycling that challenge traditional paradigms and prioritize *Green Chemistry*, efficiency, and material circularity. Two key case studies will be highlighted. The first investigates an electrochemical route for selectively recovering critical metals from spent LIB cathodes. By leveraging controlled electrochemical deposition, this method enables the targeted separation of copper and manganese, yielding high-purity materials suitable for direct reuse. The second study presents a novel combination of hydrometallurgical extraction and electrocrystallization to recover lithium with minimal chemical waste. Using a liquid gallium electrode, lithium is extracted and precipitated as lithium carbonate, demonstrating an efficient, closed-loop recovery system. By integrating electrochemical and *Green Chemistry* principles, these alternative strategies offer scalable and sustainable solutions that reduce environmental impact and support a truly circular battery economy. This talk will challenge conventional recycling perspectives and propose a vision for the future of LIB sustainability—one where waste becomes a valuable feedstock rather than an environmental burden.

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Track Classification: Future Technologies: Critical Raw Materials (including possible toxicity and environmental impact)

Contribution ID: **4** Type: **Abstract TEC2ZERO**

Hydrogen Economy vs. Hydrogen Embrittlement: Indirect Electrochemical Determination of Hydrogen Diffusion in Steel

Hydrogen has reemerged in recent years as a promising environment-friendly energy carrier that can help reduce the world's dependence on fossil fuels. Despite its unique advantages, there are still challenges regarding the storage and transportation of hydrogen. Specifically, the phenomenon of hydrogen embrittlement (HE) in metals can hinder the widespread use of hydrogen. This study focuses on the analysis of hydrogen embrittlement and hydrogen permeation through metals, with an emphasis on high-strength and duplex-steels. Various steel types were evaluated for their hydrogen permeation properties using a simplified version of the Devanathan–Stachurski permeation cell to measure the diffusion constants and breakthrough times in different steel grades. In combination with Extended X-ray Absorption Fine Structure (EXAFS) analysis, the results indicate that hydrogen embrittlement is dependent on the steel grade and that the manufacturing method plays a key role. Our methodology using indirect electrochemical determination offers rapid and reproducible hydrogen diffusion, providing insights for the development of efficient hydrogen storage systems utilizing steel.

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Co-author: Prof. SLABON, Adam

Track Classification: Materials Flow: Life-Cycle Analysis

Contribution ID: **5** Type: **Abstract TEC2ZERO**

Global Circular Economy –socio-ethical justice and challenges for science

Probelms of Global Circular Economy linked to socio-ethical justice and challenges for science will be critically discussed from a global perspective.

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Track Classification: Future Technologies: Critical Raw Materials (including possible toxicity and environmental impact)

Contribution ID: **6** Type: **Abstract TEC2ZERO**

Curative Congestion Management Service Models for Examination of their Signal Transmission Reliability

The move towards carbon-neutral electrical energy generation poses new tasks for the electrical transmission grid (>200 kV). Investment into curative congestion management is one viable alternative as per the InnoSys 2030 project [1], in order to not only bridge the gap towards large-scale expansion of the transmission grid, but also to reduce costly preventive redispatch measures. These innovative, curative congestion management measures require signals to be passed between sensors, actors and control centers within the grid reliably, using a communication network operated by transmission system operators [2, 3]. Interpreted as a service to be delivered by the communication network, it is possible to define communication models. These models –if applied to a set of sensors detecting a congestion, a set of actors solving the congestion, and a grid control center supervising the curative measure –predict how the communication is facilitated in detail when conforming to the specific model's boundary conditions and parameter set. This communication sequence is then used to algorithmically create reliability block diagrams, which in turn deliver reliability figures for the observed service through analysis, e.g., via minimal cut sets [3].
This contribution expands upon the already abstractly defined sequence model for curative congestion management, of which the Single-Pass Model (only one possible measure per contingency) for Special Protection Schemes has already been specifically defined, including how a reliability block diagram is derived from it [4]. Here, the remaining centralized variant of the Single-Pass Model is defined similarly, and then both are used to define the centralized and Special Protection Scheme Multi-Pass Models (multiple sequential backup measures per contingency). All models are compared through a fictional communication network, inspired by a real counterpart operated by a real transmission system operator. Advantages and disadvantages when implementing the curative congestion management service according to each model are highlighted.

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Track Classification: Future Technologies: Energy Efficiency

Contribution ID: **7** Type: **Abstract TEC2ZERO**

Machine Learning basierte Entwicklung von energieeffizienten Filtern für den Transport von Wasserstoff

Der zukünftig erhöhte Wasserstoffbedarf rückt den Transport über Pipelines in den Vordergrund. Durch lange Transportwege muss dieser regelmäßig auf seinen Ausgangsdruck verdichtet werden. Zur Komprimierung sind entsprechende Kompressoren notwendig, welche mit Filtern ausgestattet werden, um die Reinheit des Wasserstoffs beim Transport zu gewährleisten. Insbesondere müssen feine Öltröpfchen, die in den ölgeschmierten Kompressoren entstehen, entfernt werden. Die Druckverluste der Filter führen auf Grund der hohen Volumenströme des Wasserstoffs zu einer beträchtlichen Verlustleistung. Ein gezieltes Design der Filtermedien ermöglicht eine Verringerung des Druckverlustes und somit ein enormes CO2-Einsparpotential. Die Herausforderung bei der Entwicklung sind die großen Skalenunterschiede zwischen den abzuscheidenden Öltröpfchen im Bereich weniger Mikrometer und den Gesamtfiltern, die in der Größenordnung von Metern liegen. Klassische Berechnungsverfahren der numerischen Strömungsmechanik (Computational Fluid Dynamics) scheitern an immensen Rechenzeiten zur Abbildung der verschiedenen Skalen. Für eine effiziente Entwicklung von Filtern sind deshalb effiziente numerische Werkzeuge erforderlich. Dazu werden Machine Learning basierte Ansätze zur Bestimmung des Strömungsfeldes mit Partikelmethoden zur Berechnung der Öltröpfchen und Ölfilmen geeignet kombiniert. Konkret werden Physics Informed Neural Networks (PINNs) zur Beschreibung des Strömungsfeldes verwendet. Durch eine gekoppelte Simulation werden basierend auf den Strömungsdaten der PINNs mit einer Smoothed Particle Hydrodynamics (SPH) Methode die Abscheidung von Öltröpfchen und das Abfließen von Ölfilmen auf den Fasern beschrieben. Damit lassen sich auch größere Filterstrukturen in akzeptablen Rechenzeiten bestimmen und erlauben somit die numerische Optimierung von Faser- und Filterstrukturen, die zu einem energieeffizienten Transport von Wasserstoff führen.

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Track Classification: Future Technologies: Energy Efficiency

Contribution ID: **8** Type: **not specified**

Analysis of the Reliability of Communication Services of a Transmission System Operator Considering Dynamic Routing for Enhanced Availability

The decarbonization of German emissions necessitates the expansion of renewable energy sources while concurrently decommissioning nuclear and coal power plants. Consequently, the geographical points of energy input are changing, prompting transmission system operators in Germany to expand and optimize the utilization of the electrical transmission grid at several locations [1]. Research projects such as InnoSys2030 demonstrate that the coordinated implementation of curative measures, alongside increased automation, can facilitate higher electrical transmission grid utilization without compromising system stability [2]. These measures require a permanent and reliable data connection before and during a curative measure [3]. Data connection can link the data source and their corresponding sinks through various types of routes like static and dynamic routes. These types of routes influence the availability of the connection, as the reliability data vary between static and dynamic routes.

In this contribution, the reliability of communication services of a transmission system operator is examined. The approach from [4] is adopted and further developed with a focus on dynamic routing. The purpose is to develop a model that combines service availability requirements and the minimum number of routes with adjusted reliability metrics through communication network protection mechanisms. This involves analyzing which network protection mechanisms are relevant for dynamic routes and how these influence the reliability data of routes. Furthermore, the contribution investigates how many alternative routes must exist in a dynamic network to hit a service-specific availability class (e.g. AC 3 high availability with 99.99 % [5]). The resulting insights are validated in an abstracted section of a real communication network of a transmission system operator.

Primary author: THÖNE, Christian

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Track Classification: Future Technologies: Energy Efficiency

Contribution ID: **9** Type: **Abstract TEC2ZERO**

Zero Narratives and threshold narratives

When communicating on climate goals, the underlying models of change are rather complex and not always intuitive. My poster addresses this problem in the transdisciplinary frame of narratology and history of ideas, by highlighting Twentieth-Century traditions of storytelling and alternative conceptualisations of epochal change. Typical zero narratives of the past are event-centred. This holds true for the military and political "zero hour"as well as for fictional variations such as in Agatha Christie's Towards Zero (1944), where the story converges towards the vanishing point of the crime. The post WW2-years used a zero narrative to describe a total reset and loss of cultural baselines, either in fiction films such as Rossellini's Germania anno zero, or anthropological essays such as Morin's L'an zero de l'Allemagne. I argue that such event-centred narratives are hardly adequate to describe climate change and politics; this inadequacy shows in the difficulty of pinpointing the "Anthropocene"to a specific date and the subsequent divergences on this issue. However, Twentieth Century history of ideas also offers an alternative mindset, which is that of the threshold narrative. The philosopher Hans Blumenberg criticizes the tendency to identify "zero points"in history. Against the zero narratives, he defends the idea of an asymptotic limit, an invisible threshold between epochs. In Aspekte der Epochenschwelle (1976), he suggests that changes in history do not occur on specific dates or turning points. One can only notice that a threshold has been crossed, not where this threshold lies precisely. No single events are sufficient to indicate profound changes such that between one epoch and another. Blumenberg's concept can not only lead to a new understanding of story analysis in narratology, but also provides a more adequate model for communicating climate goals such as that of a development "towards zero carbon and zero waste".

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Track Classification: Economy, Management and Education: Communication for Managing Change

Contribution ID: **10** Type: **Abstract TEC2ZERO**

Smart Grid Laboratory as Testing Environment for innovative Technologies and Key Component for Knowledge Transfer

Abstract
Building upon the initial concept and implementation of the Smart Grid Laboratory at the University of Wuppertal, this paper presents recent advancements that significantly broaden its scope for research, development, and education in the field of smart grids. The laboratory has been enhanced with remotely controllable circuit breakers, allowing dynamic reconfiguration of the grid topology. A grid-forming inverter pair enables microgrid operation of the laboratory, facilitating the study of grid reconstruction strategies. Furthermore, the integrated frequency converters are used to simulate various energy storage technologies, supporting the evaluation of their impact on grid stability and flexibility. The laboratory was used as a field test environment for a platform for conducting peer-to-peer electricity market simulations, providing valuable insights into future decentralized trading models and promoting energy efficiency at the local level. In addition to research activities, the laboratory now plays a central role in a university course focused on smart grids, offering students practical insight in the proper use of modern smart grid equipment and real-world grid automation systems. These developments position the laboratory as a key enabler for both innovation and education in the transition towards intelligent, decentralized energy systems.

Motivation
Germany's 2025 coalition agreement places strong emphasis on accelerating the energy transition through digitalization, decentralized markets, and innovation-friendly regulation. However, real-world implementation of smart grid concepts still faces hesitation due to infrastructure risks and limited testing environments. This gap between political ambition and technical readiness underscores the need for safe, practice-oriented validation spaces. The Smart Distribution Grid Laboratory contributes to bridging this gap by aligning research and education with national energy policy goals. It enables the development of future-proof solutions and supports the training of skilled professionals—both essential to realizing a secure, intelligent, and citizen-oriented energy system.

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Track Classification: Future Technologies: Energy Efficiency

Contribution ID: **11** Type: **Abstract TEC2ZERO**

Simulation-Based Quantification of CO_2 Savings in Cellular Energy Systems

Despite significant progress in Germany's energy transition, substantial potential remains for reducing CO_2 emissions within the energy sector. In 2023, the energy industry accounted for 30.5% of total emissions, making it the largest emitter, even though renewable energy sources contributed 52% to electricity generation. This duality highlights the scope for further renewable energy expansion while emphasizing that decarbonization must extend beyond electricity production to encompass sectors such as buildings, mobility, and industry. Electrification emerges as a pivotal strategy to lower residual emissions across these domains and meet climate protection targets. However, the shift from centralized fossil-fuel power plants to numerous decentralized renewable sources, coupled with the supply of newly electrified loads, poses complex challenges to the energy system, including the integration of renewables, grid stress, and system stability maintenance. These issues necessitate innovative approaches to advance the energy transition comprehensively. Cellular energy systems offer a promising solution by restructuring the energy system into decentralized units grounded in energetic subsidiarity. This framework leverages technical and informational advantages to address the demands of a future energy system comprising thousands of small-scale units, ensuring compliance with technical and ecological constraints—such as reliable energy provision and greenhouse gas emission reductions—in a cost-effective manner while promoting operational continuity and investment incentives. This study introduces the concept of cellular energy systems and details a simulation environment designed to model multimodal energy cells. It investigates energy demands for electricity, heat, and mobility, evaluating the effects of optimally harnessing renewable generation potentials and local flexibility options on CO_2 emissions. By quantifying greenhouse gas emissions, the research elucidates the contribution of cellular energy systems to emission reductions.

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Track Classification: Future Technologies: Energy Efficiency

Contribution ID: **12** Type: **Abstract TEC2ZERO**

Automated Optimal Placement of Distribution Substations for Future Supply Tasks

The necessary electrification of the mobility and heating sector and integration of distributed energy resources as part of the energy transition to achieve a zero-carbon society is causing frequent technical limit violations (TLV) in distribution networks. The capacity of existing distribution substations (DSS) is often exceeded, necessitating network separation. To optimize the network separation, this contribution introduces an automated approach for optimal placement of new DSS within large-scale low-voltage network areas. It minimizes total costs and civil engineering measures. It therefore also reduces the environmental impact of network expansion.

The approach identifies optimal DSS positions by combining spatial data and network conditions such as existing network topology and TLV (transformer overloads, line overloads and voltage violations). Initially, the spatial data is used to identify potential positions for placement of new DSS. The approximated costs for fixing TLV are determined for each DSS and feeder. The reduction in costs for each potential DSS position are determined considering the proximity to overloaded DSS and feeders. This cost-reduction is offset against the costs for construction and integration of the new DSS, resulting in net savings. After selecting the position with the highest net savings, remaining TLV are updated for all proximate DSS and feeders. This process continues iteratively until no positions with positive net savings remain.

After determining the optimal positions, DSS are integrated into the network topology by performing a reconfiguration that separates affected networks around the new DSS. Two setups of automated planning for the network area are compared regarding total costs and length of needed line measures: One using the base topology and another incorporating the new DSS. The results prove effectiveness in not only reducing total costs but also necessary civil engineering measures.

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Figure 1: Promotional Logo BMWK

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Track Classification: Future Technologies: Energy Efficiency

Contribution ID: **13** Type: **Abstract TEC2ZERO**

Heat and Spin: Analyzing catalysts and depolymerization products using Thermoanalysis and Nuclear Magnetic Resonance

The production of high-quality chemicals based on the efficient use of sustainable resources has become an urgent global concern. In this context, the use of renewable starting materials such as different lignins as alternative to oil-based materials has been receiving increasing attention for years. Among these resources lignin is the second most abundant macromolecule on earth and technical lignins are potential sources for the production of important chemical building blocks. They can be successively depolymerized yielding valuable aromatic and aliphatic products, but this requires the production and use of stable and efficient catalytic systems and sustainable processes such as depolymerization by electrocatalytic methods. In order to further optimize catalyzed reactions, both the applied catalytic materials and the reaction products have to be thoroughly characterized by suitable methods.
Two of these methods are *Differential Scanning Calorimetry (DSC)* combined with *Thermogravimetry (TG)* and *Nuclear Magnetic Resonance (NMR)* spectroscopy. *DSC/TG* is a versatile method for investigating both the thermal stability of a novel catalyst and the stability of the obtained product. *NMR spectroscopy* is one of the most widely used routine analytical methods in research and development laboratories worldwide. With this method, the products obtained by electrochemical catalysis can be determined unambiguously and non-destructively. Furthermore, *solid-state NMR* offers a highly useful complement to the findings of electron microscopy and X-ray diffraction and absorption methods for the characterization of solid materials or nitrogen-containing catalyst systems. This talk will put a spot light on these analytical methods and their use within the endeavor of finding new and sustainable reactions and their required catalysts.

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Track Classification: Materials Flow: Waste as Feedstock

Contribution ID: **14** Type: **Abstract TEC2ZERO**

Vulnerability Assessment of Electrical Distribution Systems to Heavy Rainfall Events and Storms

Climate change consequences are evident in more frequent extreme weather events such as heavy rainfall, heatwaves, and severe storms [1, 2]. These events will become more intense and frequent, posing major challenges to the reliability and efficiency of electrical distribution systems [3, 4]. To address this, operators of electrical distribution systems need to evaluate future extreme weather risks and identify vulnerable equipment. Both meteorological and site-specific analyses are needed, as weather data alone lacks the required granularity, usually reported at municipal, district, or city level rather than individual equipment loca-tions [5].

This contribution focuses on assessing the vulnerability of distribution system equipment during heavy rain-fall and storms. Specific impacts of each weather event are defined, followed by the identification of rele-vant influencing factors. For heavy rainfall, these include equipment location in flood-risk zones, flood depths, surface runoffs, and sinks. For storms, relevant factors include wind-exposed locations due to to-pography and potentially damaging trees. The basis for both types of analysis are the freely available digi-tal terrain and surface models. The relevance of topographic influencing factors for vulnerability assessment during heavy rainfall events has already been addressed in a previous contribution presented at the CIRED Workshop in Chicago.

Vulnerability is determined by assigning failure probabilities to each influencing factor using threshold val-ues. For example, secondary substations show a markedly increased vulnerability when exposed to impacts from entire trees, as opposed to mere contact with tree canopies. Then, the individual influencing factors are aggregated for each extreme weather event, depending on their interdependencies and impact.

This methodology helps operators identify at-risk equipment and implement suitable countermeasures, im-proving system resilience. By enabling proactive planning and adaptation, it supports the development of resilient, climate-adaptive and energy efficiency distribution systems. The method is applied and validated using data from a German distribution system operator.

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Track Classification: Future Technologies: Energy Efficiency

Contribution ID: **15** Type: **Abstract TEC2ZERO**

Evaluation of Regionally Conditioned Climatic Hazards Affecting Electrical Distribution Systems during Heatwaves and Cold Spells

Ongoing climate change is accompanied by an increase in the frequency and severity of extreme weather events, including heavy rainfall, extreme heatwaves and cold spells [1, 2]. These events represent climatic hazards that can significantly affect electrical distribution systems, potentially leading to power outages [3]. To achieve maximum energy efficiency in the electrical distribution system, a resilient power supply system is essential. This requires the identification of vulnerable equipment and the evaluation of appropriate countermeasures.

Beyond analyzing the general climatological frequency of such events, this contribution focuses on region-specific conditions that influence their local impact. For this purpose, publicly available datasets - including digital elevation models, building structures, and road networks - are used to examine prevailing environmental parameters. These parameters inform a vulnerability assessment by linking hazard exposure with site-specific factors affecting the resilience of the electrical distribution system.

Extreme heatwaves and high temperatures can cause individual equipment to fail or degrade, particularly in secondary systems such as control and protection devices. These hazards are exacerbated by the urban heat island phenomenon, where densely built and sealed city centres exhibit significantly higher temperatures than surrounding rural areas [4]. Accordingly, influencing factors such as building density, surface sealing, and vegetation type are central to evaluating heat-related impacts.
In contrast, the same factors can mitigate rapid temperature drops during cold spells by retaining heat. However, additional hazards such as snow and ice must also be considered. In this context, other influencing factors - including slope inclination, slope orientation, and regional altitude - become increasingly relevant.

The presented analysis enables the identification of vulnerable equipment and supports the evaluation of locally adapted mitigation strategies to improve the resilience and hence the efficiency of electrical distribution systems. The methodology is applied to the supply area of a German distribution network operator.

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Track Classification: Future Technologies: Energy Efficiency

Contribution ID: **16** Type: **Abstract TEC2ZERO**

Integration of Photovoltaics into Microgrids for resilient Backup Power Supply of critical Infrastructure

The decarbonization of energy systems requires not only the substitution of fossil fuels with renewable sources but also the development of robust supply concepts for crisis scenarios. In particular, during a prolonged blackout, the continued power supply of critical infrastructure (CRITIS) is essential to mitigate societal and economic damage. As part of the research project SiSKIN Applied at the University of Wuppertal, the potential contribution of photovoltaic (PV) systems to the partial supply of CRITIS within microgrids is being investigated. The objective is to integrate decentralized, emission-free generation capacities and modern storage technologies into the grid restoration process following a blackout.

To this end, a realistic low-voltage test grid was established at the university's Smart Grid Laboratory, enabling the integration of PV systems in an isolated grid environment. Various control and regulation concepts were developed and implemented to maximize the grid-supportive potential of volatile PV feed-in. The results demonstrate that PV systems, when operated with frequency-dependent feed-in characteristics, can effectively support and relieve conventional black-start capable power plants during blackout scenarios. This contributes to prolonging the operational duration of these units given their limited fossil fuel reserves, thereby improving the overall carbon footprint. Furthermore, PV-based energy supply was shown to enable the stepwise expansion of the microgrid, allowing the temporary inclusion of additional CRITIS elements.

The findings underscore that the use of renewable energy sources in emergency scenarios is not only feasible but also beneficial to grid resilience. However, successful implementation at the distribution grid level requires comprehensive contingency planning and improved controllability of decentralized energy resources. These results contribute to the development of low-emission, resilient energy systems and support the goals of the initiative towards Zero Waste and Zero Carbon.

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Track Classification: Future Technologies: Energy Efficiency

Contribution ID: **17** Type: **Abstract TEC2ZERO**

Automated and Georeferenced Expansion of District Heating Networks for Cross-Sectoral Energy Planning

The transformation of the heating sector represents a central challenge on the path to climate neutrality. District heating networks play a particularly important role in densely populated urban areas, as they enable the efficient integration of renewable heat sources while supporting the gradual replacement of fossil fuels. The legally mandated, comprehensive municipal heat planning framework provides a binding structure for implementing this transition systematically, data-driven, region-specific manner, based on georeferenced infrastructure data from a geographic information system (QGIS).
Beyond strategic considerations, the technical analysis of existing supply infrastructures is gaining importance. Cross-sectoral energy planning requires the integrated consideration of electricity, gas, and heating networks. This paper focuses on the redevelopment of district heating infrastructure, whose transformation—through the conversion of existing networks, the integration of new consumers, and the expansion into previously unserved areas—necessitates detailed hydraulic and thermal modeling.
These challenges are addressed through the development of a data-driven, automated approach for the conversion, expansion, and assessment of district heating networks. Georeferenced data are transferred into the Python-based simulation environment pandapipes. These are based on real infrastructure information provided by a distribution system operator. The analysis centers on an urban district with high heat demand density, chosen as a representative case since district heating networks are particularly economically and technically viable in such areas.
The planned network expansion is aligned with existing electricity distribution lines and house connections, starting from a suitable peripheral point of the existing network. In addition to the topological design, supply and return lines as well as heat exchangers are dimensioned. The objective is to conduct hydraulic and thermal simulations to evaluate the technical feasibility and efficiency of the planned network. This approach demonstrates, how georeferenced data can be used for automated hydraulic and thermal simulations, providing a solid foundation for further cross-sectoral analyses.

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Track Classification: Future Technologies: Energy Efficiency

Contribution ID: **18** Type: **Abstract TEC2ZERO**

Automated Detection of Anthropogenic Rare Earth Element Contaminations

The rare earth elements (REEs) are among the most crucial metals for high-tech and green energy applications and are considered critical raw materials. For example, neodymium (Nd) and dysprosium (Dy) are major constituents of wind turbines, with as much as several hundred kilograms in a single wind turbine magnet. The progress of high-tech applications and E-mobility will increase the global demand for REEs. However, the increasing usage will inevitably result in an elevated anthropogenic input of critical raw materials, such as REEs, into natural environments. Such emerging contaminants are already ubiquitous in river waters, seawater, and even tap water worldwide. Since many critical raw materials may harm living organisms when exposed to elevated concentration levels, monitoring these materials in Earth's ecosystems will become a crucial task in the near future. This monitoring requires extensive data, some of which are already available through scientific publications and databases. Thus, there is a need for solutions that assist in the surveillance of large environmental datasets.
As part of the QuARUm project, we transferred the geochemical domain expertise on the natural behaviour of REEs into a data assessment method that automatically detects anthropogenic REE contaminations. In the future, we aim on continuing the work on developing low-code and easy-to-use data analytics that simplifies working with REE related samples. This line of work aims to improve the low-code language used in the data analytical process and increase the replicability of data processing by automating it.

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Track Classification: Future Technologies: Critical Raw Materials (including possible toxicity and environmental impact)

Contribution ID: **19** Type: **Abstract TEC2ZERO**

Photocatalytic Depolymerization of Sodium Lignosulfonate in Seawater Using Anthraquinone-2-Sulfonate as a Photocatalyst

The valorization of biomass-based waste products such as lignin or lignosulfonates to produce value-added compounds through depolymerization is of great importance in tackling the problems arising from the world's dependence on fossil-based resources. Especially interesting are lignosulfonates because of their water solubility and the possibility of promoting reactions without the need for harsh conditions such as high base loadings. In this project, the commercially available, non-toxic, and water-soluble anthraquinone-2-sulfonate is employed as a photocatalyst to depolymerize sodium lignosulfonate under mild conditions. The reaction is carried out in aqueous sodium chloride solution, which stabilizes the catalyst, and can proceed at room temperature and under ambient air, using UV LED irradiation as the driving force. The solubility of both catalyst and substrate in water eliminates the need for strong bases, other solubilizing agents, or organic solvents. The progress of depolymerization is monitored using various analytical techniques, which clearly reveal the breaking down of native sodium lignosulfonate. UV-vis measurements at different times reveal a significant decrease in the concentration of aromatic groups accompanied by a color change in the solution from deep brown to transparent and colorless. While NMR and IR spectroscopy indicate that structural changes occur over time, the key structural motifs are retained, suggesting that the resulting lower molecular weight compounds preserve some of the original functionalities. Notably, the reaction proceeds even in untreated and unfiltered seawater obtained directly from the Baltic Sea, without the need to resort to model compounds or idealized reaction conditions. The ability to conduct the reaction in seawater could eliminate the need for purified solvents, simplifying the process and lowering overall costs. This approach highlights a promising direction for biomass valorization, offering both a sustainable and efficient alternative.

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Track Classification: Materials Flow: Waste as Feedstock

Contribution ID: **20** Type: **Abstract TEC2ZERO**

Sustainable Recycling of Lithium-ion Batteries

Lithium-ion batteries power much of today's technology, but their growing use brings serious environmental and ethical concerns. These include limited supplies of key materials like lithium, pollution from mining, and unsafe working conditions. Recycling these batteries offers a promising way to reduce the need for new raw materials and lessen the environmental burden. Current recycling methods—such as high-temperature processing, chemical extraction, and newer techniques like using microbes or directly reusing parts—show potential, but they still face big challenges in cost, safety, and scaling up. This presentation takes a close look at these methods to see if they' re moving beyond small improvements and toward truly sustainable solutions. By focusing on efficiency, environmental impact, and how easily these methods can be expanded, we point to the urgent need for a big-picture approach. This includes considering every battery part, using eco-friendly chemistry, and connecting science, industry, and policy. Moving in this direction is key to building a circular economy and making battery use cleaner and more responsible. In my presentation, I would like to show how we aim to advance the recycling of LIBs in the future through new methods that align with the *12 Principles of Green Chemistry*, and provide an overview of what future recycling processes could look like.

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Contribution ID: **21** Type: **Abstract TEC2ZERO**

Nanostructured and Atomically Dispersed Catalysts on Biomass-Derived Supports for Lignin Depolymerization

The urgent need to replace fossil-based resources with sustainable alternatives calls for innovative strategies in biomass valorization. Among these, the efficient use of lignocellulosic biomass has proven particularly promising. Although a complete substitution of fossil fuels is unlikely, biomass can serve as a viable and renewable feedstock for a significant fraction of chemical production. To avoid conflicts with food supply, research efforts must focus on second-generation (2G) biomass sources—such as agricultural residues, food processing by-products, and invasive plant species.
Electrochemical lignin depolymerization has emerged as a powerful approach for the production of valuable chemical intermediates. Historically, bulk electrodes composed of carbon, nickel, lead, platinum, or copper have been used, but their limited structural tunability restricts both reactivity and selectivity. Overcoming these limitations requires a transition to nanostructured systems. Nanoparticle-based electrodes have already shown improved catalytic performance, while further advances can be achieved using single-atom (SACs) or dual-atom catalysts (DACs), in which nearly every metal atom contributes as an active site, enabling close to 100% atomic efficiency.
These catalysts rely on stable support materials, with carbon-based matrices being widely applied. To enhance the overall sustainability of the system, carbon supports derived from waste biomass —such as spent coffee grounds, brewers' spent grains, or invasive plants like Japanese knotweed —have been successfully implemented. Iron, nickel, and copper nanoparticles or atoms dispersed on such supports have proven effective in reductive electrochemical lignin depolymerization. Catalyst structures and dynamics have been characterized using XRD, XPS, SEM-EDX, LEIS, TEM, and *in-operando* XAS. The time resolution of modern synchrotron-based spectroscopy enables the investigation of structural and electronic transformations on millisecond to hour timescales, providing insight into the behavior of catalysts under reaction conditions.
The resulting depolymerization products offer synthetic potential and support the development of a more sustainable, circular chemical economy.

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Track Classification: Materials Flow: Waste as Feedstock

Contribution ID: **22** Type: **Abstract TEC2ZERO**

Grinding Sludge Waste from High-Alloy Tool Steel through a Smelting-Metallurgical Process

This study explores the upcycling of grinding swarf, a by-product of subtractive machining, into semi-finished cast products by recovering silicon carbide (SiC) and aluminum oxide (Al_2O_3) abrasives and using them as alloying additions. Two cold-work tool steels, X153CrMoV12 (1.2379) and 80CrV2 (1.2235), were modified, with emphasis on X153CrMoV12 due to its higher content of critical alloying elements. The recycling route comprised the thermal removal of coolant residues, particle separation by sieving and magnetic purification, and direct alloying of the residual abrasives during casting. Al_2O_3 floated into the slag while SiC fully dissolved, raising the melt's carbon content from 1.53 mass% to 1.78–2.51 mass% and its silicon content from 0.35 mass% to 0.94–1.73 mass%. Using up to 31.0 mass% recyclates met the X153CrMoV12-1 standard; relaxing the silicon target to ~1.0, mass% allowed the incorporation of up to 68.0 mass% recyclates. Thermodynamic simulations predicted a similar solidification sequence and microstructure in recycled and reference alloys. Microstructural investigations of the cast samples by SEM and the methods adapted to it (EBSD) revealed an austenitic as-cast matrix with blocky M_7C_3, MC, and $M_{23}C_6$ carbides. After quenching, comparable hardness levels were achieved between the three steel grades (800 HV1 vs. 806 HV1 vs. 800 HV10). Upon tempering at 500 ℃, hardness differences became apparent (618 HV1 vs. 664 HV1 vs. 726 HV10). Microscopically, all materials exhibited a microstructure consisting of a metal matrix of tempered martensite with a high-volume fraction of carbides.

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Track Classification: Materials Flow: Waste as Feedstock

Contribution ID: **23** Type: **Abstract TEC2ZERO**

Polymer functionality by degradation: the activation of mechanophores in a ball mill

Mechanical stress leads to cracks and failures in materials and can also induce bond scission and the formation of radical species. Just as a UV lamp can accelerate photo-aging, mechanical stress applied via ball milling (or in another way) can be used to speed up material degradation and simulate mechanical wear over time.
Additives, especially antioxidants, are commonly added to polymers and it has already been studied how the properties of materials change in their presence and how they interact with the material to slow down the degradation process. In this study BHT (butylated hydroxytoluene) was chosen as antioxidant for polystyrene (PS).
When a mechanophore is included within polymer chains, they typically promote selective bond scission, but not always at the intended site, raising questions about mechanophore selectivity. This is due to the intrinsic complexity of polymers compared to small molecules, with numerous variables influencing the outcome. Therefore, it is crucial to investigate whether the presence of additives can enhance the selectivity of mechanophore-induced bond scission, in order to achieve better control over polymer degradation.

Using a combination of mechanical testing, spectroscopic analysis and GPC measurements, and comparing samples with and without BHT, this behavior is systematically studied. This will be important for steering mechanical stress to trigger functional responses with molecular precision.

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Track Classification: Future Technologies: Critical Raw Materials (including possible toxicity and environmental impact)

Contribution ID: **24** Type: **Abstract TEC2ZERO**

Mechanochemically Self-Immolative Polymers

Polymers are important for humanity from daily life usage to advanced science and technology. Considering the degradation rate of polymers in nature and associated difficulties in recycling monomers by depolymerization, the widespread polymer usage poses a significant environmental hazard generating waste in a linear economy. Thereupon, the widespread use of self-immolative polymers, macromolecules can undergo simultaneous depolymerization with trigger activation, for such applications could be a potential solution to these drawbacks. In this study, our plan is to design mechanochemically active self-immolative polymers for functional materials production. Methodologically, carbamoyloxime scaffolds, have been developed by our research group, applied as mechanophore to trigger two different self-immolation approaches. The first approach is directly triggering the self-immolation of 4-aminobenzylalcohol-based poly-carbamates by the activation of aniline units. On the other hand, the second approach uses an indirect trigger, including base-promoted depolymerization of poly(butyl cyanoacrylate) via mechanochemical activation of organic superbases. By combining the mechanochemical approach with self-immolative polymers, it is aimed to achieve more selective self-immolation and complete depolymerization of polymers following mechanochemical activation. This selective self-immolation potentially render polymers a more sustainable alternative for several fields from material science to biotechnology.

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Track Classification: Future Technologies: Critical Raw Materials (including possible toxicity and environmental impact)

Contribution ID: **25** Type: **Abstract TEC2ZERO**

GraphRAG-Based Product Selection: Multi-Criteria Sustainability in Construction

Multi-criteria decision-making for product selection in construction is becoming increasingly important, as purely technical and economic evaluations can no longer capture the complex demands of sustainability. In particular, ecological and socio-cultural criteria exert a decisive influence on the life-cycle assessment (LCA) of building materials and are embedded in certification systems such as DGNB and LEED, as well as in the EU Taxonomy and various ecolabels. Against this backdrop, an ontology-based decision-support system leveraging GraphRAG is under development. It systematically extracts relevant information from unstructured sources—technical data sheets, safety data sheets, and Environmental Product Declarations (EPDs)—represents this information within a knowledge graph, and makes it interactively queryable in combination with large language models (LLMs).

By integrating semantic ontology with AI-driven language processing, GraphRAG enables automated responses to complex, multi-hop queries: planners, contractors, and sustainability auditors receive context-aware recommendations that interlink technical performance, cost efficiency, and both ecological and socio-cultural dimensions. For example, the system can identify low-emission insulation materials that not only satisfy energy-performance requirements but are also manufactured under socially responsible production conditions. To validate the system, structured expert interviews were conducted with stakeholders from architecture, site management, and certification bodies. These interviews captured typical information needs and decision workflows, from which a set of “must-have”queries was derived—queries that GraphRAG must answer reliably and transparently. Particular emphasis was placed on performance under multi-query scenarios, such as the concurrent evaluation of life-cycle costs, carbon dioxide (CO_2) equivalents, and health-relevant emissions.

Evaluation results demonstrate that GraphRAG provides significant time savings and enhanced transparency in the decision-making process compared with conventional research methods. In the long term, this approach promises to systematically promote more sustainable construction products and to streamline the practices of product selection and certification.

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Track Classification: Materials Flow: Life-Cycle Analysis

Contribution ID: **26** Type: **Abstract TEC2ZERO**

Forecast of the distribution of heat pumps based on building structure data as part of cross-sectoral energy network planning

In order to reduce greenhouse gas emissions, the degree of electrification of the heating and transport sectors is increasing, among other things. This is creating new challenges for the energy networks. A cross-sectoral view of the energy system is required in order to plan the energy networks and thus prepare them for future requirements. Such a holistic approach is currently the subject of various research projects under the heading of cross-sectoral energy network planning. In this paper, one possibility of cross-sectoral energy network planning is explained and one component of the approach is discussed in more detail.
The cross-sectoral energy network planning described in this paper is aimed at re-planning the energy networks in existing areas. New development areas are not taken into account. The approach is based on building structure data. In a first step, individual buildings in a test area are categorized and grouped into typical districts. Irrespective of the categorization and district division, the buildings are examined for the probability of adoption of decentralized energy systems, such as heat pumps or photovoltaic systems. The probabilities are used to allocate decentralized energy systems to the buildings in the test area. The distribution of energy systems is validated using Germany-wide scenarios, which are regionalized to the test area. The scenarios differ, for example, in terms of their degree of centrality in relation to the energy supply. The electricity, gas and heating networks are planned based on the assigned decentralized energy systems. Different recommendations for action are developed for the districts identified in the first step, depending on the prevailing building structure.
This paper examines the cross-sectoral energy network planning process and explains in detail the regionalization of Germany-wide scenarios at building level using the example of heat pumps.

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Track Classification: Future Technologies: Energy Efficiency

Contribution ID: **27** Type: **Abstract TEC2ZERO**

Die Rolle des natürlichen Wasserstoffs im zukünftigen globalen Energiemix

Weißer Wasserstoff, also natürlich entstandener Wasserstoff, gewinnt zunehmend an Bedeutung als bislang unterschätzte und potenziell disruptive Energiequelle im globalen Energiemix. Er entsteht durch geochemische Prozesse wie Serpentinisierung tief in der Erdkruste und sammelt sich über geologische Zeiträume in unterirdischen Reservoiren an. Diese Form der natürlichen Wasserstofferzeugung kommt ohne CO_2-intensive Vorprozesse oder externen Energieeinsatz aus, was sie im Ver-gleich zu etablierten Verfahren besonders umweltfreundlich und kosteneffizient macht. Sie kommt einer standardisierten Gasförderung sehr nahe.

Aktuelle Pilotprojekte, etwa in Mali, Frankreich oder Albanien, belegen sowohl die technische Machbarkeit als auch die Reinheit und Nutzbarkeit der geförderten Ressourcen. Erste techno-ökonomische Analysen schätzen die Förderkosten auf nur etwa 0,5 bis 1 $ pro Kilogramm. Ein Wert, der deutlich unter dem von grünem Wasserstoff liegt. Letzterer wird derzeit, abhängig von Standort und Energiepreisen, mit etwa 2 bis 7 € pro Kilogramm veranschlagt. Auch der ökologische Fußabdruck ist gering. Mit rund 0,4 CO_2/kg zählt weißer Wasserstoff zu den emissionsärmeren Formen verfügbarer Wasserstoffenergie. Dies ist hinsichtlich des weltweit weiter an-steigenden Energiebedarfes von äußerster Bedeutung.

Die globale Ressourcenschätzung liegt im zweistelligen Teratonnenbereich. Studien eines amerikanischen Forscherteams, aus dem Jahr 2024, haben errechnet, dass sich potenziell bis zu 6,2 Billionen Tonnen weißen Wasserstoffs in der Erde befinden können. Selbst eine teilweise Nutzung würde ausreichen, um den weltweiten Energiebedarf über viele Jahrzehnte zu decken. Somit könnte er eine tragende Rolle bei der Dekarbonisierung von Industrie, Mobilität und Stromerzeugung einnehmen. Trotz dieser Potenziale bestehen noch Herausforderungen bei der Erkundung, Erschließung, rechtlichen Regulierung, Sicherheit usw.. Gleichzeitig wächst das internationale Interesse rapide mit Beteiligung großer Energieunternehmen und staatlicher Explorationsprogramme. Langfristig könnte sich natürlicher Wasserstoff zu einer Schlüsselressource der globalen Energiewende entwickeln; ökologisch,
gesellschaftlich, wirtschaftlich und geopolitisch.

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Track Classification: Future Technologies: Energy Efficiency

Contribution ID: **28** Type: **Abstract TEC2ZERO**

Metal-Isolator-Graphene Diodes for On-Chip Energy harvesting

On-chip energy harvesting is an emerging field, driven by the demands of mobile sensor systems for autonomous operation. For operation conditions under daylight or indoor light conditions, photovoltaic devices offer an easy and efficient way to cover the energy demands of sensor systems, having the potential of delivering power levels up to $20mW/cm^2$. Recent studies on metal-insulator-graphene diodes (MIG-diodes) have shown that they can operate as photodiodes and photovoltaic devices when quantum dots (PbS) or an inorganic perovskite (CsPBBr3) are deposited on top, while their total device size can be reduced to µm scale, making them ideal candidates for on-chip energy harvesting. Interestingly, MIG-diodes with perovskite exhibit an unconventional photovoltaic effect, i.e. zero bias photocurrent in the forward direction of the diode, unlike conventional silicon-based solar cells.
This poster demonstrates the potential for producing micron-scale photovoltaic devices with different absorption characteristics using MIG-diodes and perovskites for on-chip energy harvesting. For this purpose, organic and inorganic perovskites were deposited onto MIG-diodes and afterwards their optoelectrical properties were investigated. Using CsPbBr3 as the photoactive material, the solar cells yielded an open-circuit voltage of about 1 V, which can further be increase due to serial connections of several devices. Furthermore, perovskites allow the absorption spectrum to be adapted from blue to red by adapting the material composition. This enables the system to be flexibly adapted to different applications and illumination conditions.

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Track Classification: Future Technologies: Energy Efficiency

Contribution ID: **29** Type: **Abstract TEC2ZERO**

Flächensuffizienter Stadtumbau

Ein flächensuffizienter Stadtumbau verfolgt das Ziel, urbane Räume ressourcenschonend und zukunftsfähig zu gestalten. Wichtige Zukunftstechnologien wie emissionsfreie Produktionsmethoden, intelligente Energienetze und integrierte Mobilitätslösungen eröffnen neue Möglichkeiten, bestehende Flächen effizienter zu nutzen. Smarte multimodale Verkehrssysteme reduzieren den Bedarf an monofunktionalen Infrastrukturen und ermöglichen eine kompakte, durchmischte Stadtstruktur.

Die Kreislaufwirtschaft spielt eine zentrale Rolle, indem sie auf lokale Produktion, kurze Lieferketten und eine maximale Wiederverwendbarkeit von Materialien setzt. Ein wesentlicher Hebel liegt im Produktdesign: Anpassungsfähige, langlebige und reparierbare Produkte tragen dazu bei, den Ressourcenverbrauch zu senken und die Inanspruchnahme zusätzlicher Flächen zu vermeiden. Der bewusste Umgang mit Materialflüssen wird damit zu einer Voraussetzung für eine nachhaltige Stadtentwicklung.

Urbanes Management erfordert flexible Organisationsformen, die dynamisch auf technologische, soziale und ökologische Veränderungen reagieren können. Regionale Produktions- und Dienstleistungsnetzwerke stärken die Resilienz städtischer Räume, indem sie Abhängigkeiten von globalen Lieferketten verringern und lokale Wertschöpfung intensivieren. Dadurch entstehen flächeneffiziente Strukturen, die zugleich wirtschaftliche Stabilität fördern.

Ein integraler Bestandteil flächensuffizienter Stadtumbaukonzepte ist die urbane Landwirtschaft. Durch die gezielte Integration produktiver Agrarflächen innerhalb der Stadt werden nicht nur regionale Ernährungssysteme gestärkt, sondern auch ökologische und soziale Qualitäten verbessert. Urbane Landwirtschaft reduziert Transportaufwände, fördert Biodiversität und bietet Möglichkeiten für gemeinschaftliche Nutzungen, wodurch multifunktionale Freiräume entstehen.

Kommunikation bildet dabei das verbindende Element innerhalb der Veränderungsprozesse. Transparente Dialogformate, partizipative Entscheidungsprozesse und gezielte Wissensvermittlung erhöhen die Akzeptanz für neue städtische Strukturen. Flächensuffizienter Stadtumbau ist daher nicht nur eine planerische Aufgabe, sondern verlangt ein integratives Zusammenspiel von technologischer Innovation, ökonomischer Anpassungsfähigkeit und sozialer Mitgestaltung.

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Track Classification: Economy, Management and Education: Communication for Managing Change

Contribution ID: **30** Type: **Abstract TEC2ZERO**

Oxidation of phenols using catalytic amounts of solid-supported IBS-based catalysts in Continuous Flow

Oxidation of phenols using catalytic amounts of solid-supported IBS-based catalysts in Continuous Flow

J.P. Nau, Dr. A. Gómez-Suárez, Prof. Dr. S.F. Kirsch

As reactive intermediates, 1,2-quinones (o-quinones) have gained importance in organic synthesis. They can undergo many kinds of follow-up reactions like [4+2]-cycloadditions[2], formal [3+2]-photoadditions with vinyl ethers[3] or 1,4-additions with nitrogen-centered nucleophiles, respectively 1,6-additions with thiols as nucleophiles[4]. A reliable method for the synthesis of o-quinones is the application of λ^5-Iodanes which show a remarkable regioselectivity favouring the formation of 1,2-quinones compared to 1,4-quinones[7]. Catalytic applications of λ^5-Iodanes for the dearomatization of phenols were first described by Ishihara and co-workers in 2012. They discovered the suitability of 2-Iodosulfonic acid (IBS)-derived catalysts which are superior to their IBX-analogues[5]. Based on this work and the solid-supported IBX (SP-IBS)-catalyzed oxidation of alcohols in flow, first published by Kirsch et al.[6], we are now developping a method for the oxidation of phenols to 1,2-quinones in flow using solid-supported IBS-based catalysts and tetrabutyl ammonium Oxone (nBu4NHSO5) as co-oxidant.

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Track Classification: Materials Flow: Waste as Feedstock

Contribution ID: **31** Type: **Abstract TEC2ZERO**

The life of a raindrop –no drop must be lost!

Traditionally, a raindrop touching streets or sealed areas will be subsequently mixed with wastewater and therefore treated in a cost- and energy-intensive cleaning process.
The originally clean raindrop is treated as wastewater in a wastewater treatment plant and leads therefore to an unnecessary CO_2 production, a reduction of the efficiency of wastewater treatment plants and finally a pollution of surface waters (due to combined sewer overflows).
But how can raindrops be prevented from becoming wastewater to reduce costs and energy and therefore CO_2 production? Every single raindrop must remain in the natural water cycle, the rainwater must remain in its blue-green environment!
A wide range of research exists in the field of sustainable drainage approaches. At the hydraulic engineering section of the University of Wuppertal two research projects on the optimization of the management of cisterns and on the implementation of blue-green-infrastructures in (existing) settlements are being carried.

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Track Classification: Future Technologies: Energy Efficiency

Contribution ID: **32** Type: **Abstract TEC2ZERO**

Reactive Power Potentials of controllable loads for enhaced efficiency in distribution grid operation

The ongoing energy transition is increasingly changing the requirements for electrical distribution grids. Reactive power provision, which has traditionally been ensured primarily by central generation units in the transmission grid, must in the future be organized in a decentralized manner. At the same time, the share of new types of electrical loads in distribution grids is rising significantly —particularly due to the widespread expansion of charging infrastructure for electric vehicles and heat pumps. These loads are often equipped with power electronic interfaces, which are in principle capable of targeted reactive power control. Systematically tapping into these reactive power potentials could represent an as-yet underutilized opportunity to improve both efficiency and stability in distribution grid operation.
The aim of this contribution is to analyze the technically usable reactive power potential of modern controllable loads and to assess their possible contribution to increasing the operational efficiency of distribution grids. The focus is particularly on reducing grid-related losses and improving voltage quality in the low- and medium-voltage levels.
For this purpose, representative grid structures with realistic load profiles and varying penetration levels of controllable loads are modeled. Using simulation-based grid analyses, the influence of reactive power utilization on grid losses, voltage regulation, and operational limits is examined. In addition, the relevant technical and regulatory framework conditions are analyzed with regard to their suitability and constraints.
This contribution aims to provide a system-level classification of the reactive power capabilities of modern loads and to identify potential levers for improving operational efficiency. The results are intended to serve as a basis for further investigations into operational strategies, incentive mechanisms, and technical standardizations, with the goal of making reactive power potentials more systematically usable in real-world grid operation.

Primary author: ZDRALLEK, Markus

Track Classification: Future Technologies: Energy Efficiency

Contribution ID: **33** Type: **Abstract TEC2ZERO**

Modeling of Radiative Heat Transfer for Energy Efficient Systems

In fire dynamics, radiative heat transfer is a crucial mechanism of energy transport and thus an important factor in flame propagation and fire spread. This applies across a wide range of scales, from small to very large, such as those encountered in building fires or wildfires. Radiative heat transfer is ubiquitous and also plays a significant role in the design and operation of energy-efficient systems. However, a detailed understanding of the spectral properties of participating media remains challenging. At interfaces and solid materials, directional and temperature-dependent behavior can further complicate the analysis.

With this poster, we present various numerical approaches to modeling radiative heat transfer—e.g., the Finite Volume Method (FVM) and Discontinuous Galerkin Finite Element Method (DGFEM)—in the context of fire dynamics. These methods can be transferred to other disciplines using the same tools but with varying levels of detail and computational effort. OpenFOAM is our primary simulation tool, as it enables the handling of highly complex geometries and can be combined with detailed species and temperature distributions. For specialized simulations, we also employ deal.II.

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Track Classification: Future Technologies: Energy Efficiency

Contribution ID: **34** Type: **Abstract TEC2ZERO**

Sustainable Design Literacy –a systemic approach through product and service innovation

In this paper we paper suggest a systemic approach to strengthen sustainable literacy through strategic design on a societal level. The UN Resource Council (2020) underscores that extending product life cycles and increasing the intensity of use is crucial for meeting climate and resource goals. Design can help to bind carbon dioxide in products and infrastructures in the long term and on a large scale—make it available for further use (Carbon Cycle). Extending product life cycles requires not only a cultural shift in production but also in consumption habits, supported by repair-friendly products and accessible services.
Against this background, we present the project Sustainable Design Literacy, launched within the Master's Program in Strategic Innovation in Products and Services. Placing repair at the heart of the circular economy, the project aims to build competencies across the entire life cycle—from design and production to use, maintenance, repair, and responsible disposal. A multi-stage roadmap to 2030 outlines three core goals: raising awareness, strengthening knowledge and skills, and creating repair opportunities.
The project specifically targets the needs of 18- to 34-year-olds because they have a significantly lower awareness of repair compared to older groups (Micklitz et al., 2022). Key elements of the concept are: legal and education-oriented measures (e.g., repair escape rooms); concepts for manufacturing companies (e.g., forms of interaction such as digital twins and repair apps); strategies for service providers (e.g., platforms and repair services); and product design (e.g., "readable"and modular products, modular designs). The concept highlights that transformation towards more sustainable forms of production and consumption need new and diverse educational formats, intelligent products and innovative business models, but also supportive policy frameworks.
To conclude, we will use the visual outputs from the project to discuss the role of design in enhancing communication among diverse stakeholders to reach sustainable literacy together.

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Track Classification: Economy, Management and Education: Product Design

Contribution ID: **35** Type: **Abstract TEC2ZERO**

Mathematical Modeling and Numerical Methods for Pricing Emission and Renewable Energy Certificates in Energy Markets

The transition to low-carbon energy systems has fostered the development of market-based instruments, such as CO_2 emission allowances (EAs) and renewable energy certificates (RECs), to reduce greenhouse gas emissions and incentivize renewable energy production. This project explores the mathematical modeling, analysis, and numerical solution of these instruments, contributing both theoretical and computational advances.

EAs are central to cap-and-trade systems, where firms trade allowances under a regulatory cap on emissions. Their price dynamics depend on multiple uncertain factors-in particular, electricity demand and cumulative emissions-and are modeled using forward-backward stochastic differential equations (FBSDEs) and related nonlinear partial differential equations (PDEs). We aim to extend existing models by incorporating feedback mechanisms and jump processes, leading to more complex semilinear partial integro-differential equations (PIDEs). Rigorous mathematical analysis ensures the well-posedness of these models, while novel numerical schemes improve computational efficiency.

A less mature but growing area of study is RECs, which are issued to renewable energy producers. Here, the certificate price depends on stochastic renewable generation and certificate accumulation. The project investigates FBSDE formulations where the existence of solutions remains an open question due to full coupling. We extend the modeling of REC dynamics and analyze the pricing of both standard (European) and advanced (American, exotic) derivatives using PDEs, complementarity problems, and expectation-based formulations. Efficient solution techniques, including finite difference, semi-Lagrangian, and Monte Carlo methods, are developed and tested.

This interdisciplinary work bridges applied mathematics, finance, and energy economics, providing valuable insights into sustainable energy market design and risk management. The models and methods developed have broad applicability in quantitative finance, policy modeling, and computational science.

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Track Classification: Economy, Management and Education: Management and Implementation

Contribution ID: **36** Type: **Abstract TEC2ZERO**

Sustainable road construction due to the use of temperature-reduced asphalts

Roller-compacted asphalt used for road construction is produced and paved at temperatures between 130℃ and 195℃. For work safety reasons, an occupational exposure limit (OEL) was set in Germany in 2019 for vapors and aerosols from bitumen during hot processing. A reduction in emissions can be achieved by using temperature-reduced asphalt. The mixing and paving temperatures are lowered by at least 20K compared to conventional asphalt. This results in fewer emissions, which leads to better working conditions. Moreover, energy consumption during asphalt production, and consequently CO2-emissions, can be significantly reduced.

Organic, mineral and chemical additives are used to ensure workability at reduced paving temperatures. Depending on their mode of action, they lower the viscosity of the binder or reduce the surface tension between the aggregate and the bitumen. This improves the processing properties of the asphalt and enables it to be compacted at lower temperatures. This is essential to ensure the functionality of temperature-reduced asphalts and to achieve the same performance properties as asphalts without temperature reduction.

For temperature-reduced asphalts to become the standard for sustainable road construction, their performance properties must be determined and proven comparable to non-temperature-reduced asphalts. As part of a research project, extensive tests were carried out on temperature-reduced and as a reference non-temperature-reduced asphalts at both the asphalt and binder levels. The test specimens produced were tested in the laboratory for their resistance to low-temperature cracking, fatigue cracking and permanent deformation at high, medium and low temperatures. Different additives were considered and both laboratory-produced and on-site mixes were used. The results demonstrate a high degree of comparability between temperature-reduced asphalts and reference asphalts. Depending on the additive used, certain properties were identified in which the temperature-reduced asphalts performed better than the reference asphalts. These results were also confirmed in the in-situ test fields.

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Track Classification: Future Technologies: Energy Efficiency

Contribution ID: **37** Type: **Abstract TEC2ZERO**

Perovskite Solar Cells for Satellites - Lightweight, Low-Cost and Resource-Friendly

Satellites are essential for modern society, supporting functions like weather forecasting, climate protection, communication, IoT, and autonomous driving. Small satellites, in particular, are becoming increasingly important due to their cost-effectiveness and ability to be mass-produced. They often rely on onboard power systems since they must operate autonomously, and the cost of launching satellites, ranging from 10,000 to 50,000 dollar per kilogram, makes every gram crucial. Traditional solar modules for space applications, though efficient, are bulky and heavy, and offer a power-to-weight ratio of less than 0.2 W/g, making power management a critical factor in satellite design.

In contrast, metal-halide perovskite solar cells offer a transformative advantage with ultrathin layers and exceptional power-to-weight ratios of up to 20 W/g, while being composed of abundant elements. Thereby they can reduce payload mass by up to 99 % compared to traditionally used solar cells, which could not only reduce launch costs but enable unprecedented mission flexibility by dramatically relaxing the power budget.

At the Chair of Electronic Devices, we are pursuing two major initiatives to leverage these advantages: the NATO funded "SpacePerCells" project, in collaboration with international academic partners in Uzbekistan, and the "PeroSat" project, supported by the European Fund for Regional Development together with local industry in NRW. In order to harness the unique properties of perovskite for space, we have to ensure operational stability. As perovskites have already proven their high resilience against ionizing radiation, we focus on two other key stressing factors in space: vacuum and atomic oxygen. To this end, we develop a novel thin-film barrier technology to create ultra-thin permeation barriers that will prevent material out-diffusion in vacuum or in-diffusion of harmful oxygen radicals, without compromising weight or electrical performance. Our initial results are promising, showing that even unoptimized thin-film barriers can extend the tolerable vacuum exposure significantly.

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Track Classification: Future Technologies: Energy Efficiency

Contribution ID: **38** Type: **Abstract TEC2ZERO**

Oxidative Cleavage of β-Substituted Alcohols in Flow

Selective cleavage and functionalization of C–C bonds remain a significant challenge in organic chemistry due to their intrinsic kinetic inertness and high thermodynamic stability.1 Throughout the last decades, numerous valuable homogeneous catalytic systems have been well established for the cleavage and functionalization of alcohols (β-substituted primary alcohols), which are abundant in biomass and promote biomass valorization.2 Despite impressive progress made in this area, an over-reliance on environmentally harmful oxidants and catalysts that exhibit low recyclability in both metal and non-metal catalysts continues to restrict most of these reaction classes and leave a gap for further development in a sustainable manner. Transitioning to heterogeneous catalysis offers several advantages over homogeneous catalysis, including facile separation, enhanced recyclability, simplified product isolation, and seamless integration into continuous-flow reactors.
Herein, we report an efficient protocol that enables direct oxidative cleavage of β-substituted primary alcohols by a solid-supported hypervalent iodine catalyst under continuous flow conditions. A wide variety of structurally distinct β-substituted primary alcohols are viable in this reaction, enabling access to secondary alcohols using TBA-Oxone® as an environmentally benign oxidant. Moreover, reaction conditions also allowed cleavage and oxidation of tetrahydrofuran-2-methanol and pyrrolidine-2-methanols to lactones and lactams, respectively. This protocol features easy scalability, broad substrate scope, excellent functional group tolerance, and recyclable catalyst up to 15 times.

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Track Classification: Materials Flow: Waste as Feedstock

Contribution ID: **39** Type: **Abstract TEC2ZERO**

Optimization of cement stone recovery in concrete recycling by thermal-mechanical treatment

In view of the high CO2-emissions of the cement industry and the growing demand for mineral aggregates, maximum recovery of cement stone and original aggregates in concrete waste must be aimed at. For example, recycled coarse aggregates can be reused in ready-mix concrete, while the separated and ground cement stone can be returned into the clinker burning process, opening the possibility to saves a significant amount of CO2-emissions, but also conserves resources by partially replacing the limestone with the secondary raw meal.

To increase the degree of recovery especially of cement stone, a processing technology combining cyclic heating and grinding was investigated. To determine the optimum combination of cyclic heating and subsequent grinding, extensive test series were performed using a conventional concrete mixture. After initial crushing, the concrete waste was thermally pre-damaged at different temperature levels with different numbers of cycles. To evaluate degree of recovery, different variations of mechanical energies were tested in a grinding process using a ball mill. To vary the crushing energy e.g. the drop height of the steel balls, their diameter and duration of grinding were changed.

It has been shown, that combined thermal-mechanical treatment increases the degree of recovery of cement stone. Recovery of fine aggregates increases with increasing temperature, steel ball size and duration of grinding. The temperature treatment alone not only increases the crushability of the coarse agglomerates, but helps to improve elemental composition of the recycled cement stone for reuse in the clinker burning process. Mechanical grinding energy alone, has no significant effect on the elemental composition of the recycled fine cement stone. In addition, increased CaO content was observed with increasing fineness of the recycled material. At high mechanical grinding energies, the quality of the coarser recycled aggregates ($\geq$ 0.5 mm) is almost comparable to the properties of geogenic aggregates.

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Track Classification: Materials Flow: Urban Mining & Secondary Raw Materials

Contribution ID: **40** Type: **Abstract TEC2ZERO**

Potential for the circular economy in the deconstruction of wind turbines

The sustainable deconstruction of wind turbines is of great importance due to the growing of renewable energies and the limited availability of resources. Forecasts by the Ramboll Research Center show that the amount of waste from deconstruction will increase drastically in the coming years. A total of 5.5 million tons of waste concrete are forecast for 2038. Due to the large amounts, solutions must be found to address this issue. The sustainable non destructive deconstruction of wind turbines could be a solution. The aim of this study is to examine the nationwide distribution of the various types of tower construction in order to assess transportation and logistics aspects and to evaluate the potential for reusing reinforced concrete segments by means of material analyses. The findings will be used to measure economic factors and dependencies with regard to reuse potential.
The methodology includes material tests on wind turbines from the Teglingen and Lorup wind farms in Germany as well as a data analysis to document the distribution of the different tower construction types. Among other things, it was found that almost all of the towers examined achieved at least the original compressive strength class and in some cases even significantly exceeded it. In addition, very low carbonation depths and high concrete coverings result in very high depassivation times. The results of the site analysis show that reinforced concrete towers make up significant proportion of the wind turbines in operation (9.8 %) in terms of the amount of material used. The data analysis also showed that the distribution of different tower types corresponds to the overall distribution in Germany.
Further research, regarding economic and ecological aspects of the reuse and deconstruction of wind turbines will be conducted in order to develop sustainable, resource-saving strategies for the construction industry.

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Track Classification: Materials Flow: Urban Mining & Secondary Raw Materials

Contribution ID: **41** Type: **Abstract TEC2ZERO**

Where Safety Meets Sustainability –Oxidations in Continuous Flow

Hypervalent iodine reagents offer powerful oxidative capabilities and have emerged as attractive, metal-free alternatives to traditional oxidation methods that often rely on toxic metals. However, their high-energy character can raise significant safety concerns, especially in traditional batch processes. In response to these challenges, we have developed a series of continuous flow methodologies that enable safer, cleaner, and more efficient oxidative transformations.

By leveraging solid-supported iodine(V) reagents, green solvents, and benign co-oxidants, our work demonstrates how flow chemistry can unlock the full potential of hypervalent iodine reagents while minimizing environmental impact and operational risk. Our continuous flow system demonstrates excellent robustness, maintaining full efficiency over at least 15 consecutive runs without significant catalyst leaching or degradation.

These systems consistently deliver high selectivity, improved reaction control, and scalability—without compromising safety or sustainability.

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Track Classification: Materials Flow: Waste as Feedstock

Contribution ID: **42** Type: **Abstract TEC2ZERO**

Enabling Sustainable Road Infrastructure: The Strategic Role of the Traffic Speed Deflectometer

Achieving zero-waste and zero-carbon goals in road infrastructure requires strategies that extend beyond construction to include the entire life cycle, based on a holistic understanding of road pavements and their condition. Conventional condition assessment methods generally focus on surface properties, neglecting the structural state of the road. This often results in misguided or suboptimal maintenance decisions, leading to avoidable material use, emissions, traffic disruptions and cost.

The Traffic Speed Deflectometer (TSD) is a continuously operating, non-destructive measurement system that enables the assessment of the structural bearing capacity of pavements at network level. While the measurement process itself is minimally invasive, the true ecological value of the TSD lies in its ability to enable timely, targeted, and proportionate maintenance interventions.

To evaluate the potential of TSD measurement data for a sustainable road asset management, extensive surveys were conducted in Brandenburg and North Rhine-Westphalia. The collected data were used to identify structurally homogeneous sections and to assess key indices such as the SCI300 and the bearing capacity number Tz, enabling a comprehensive understanding of the pavement's condition.

Accurate knowledge of the structural condition ensures the selection of appropriate maintenance measures at the right time and location. This prevents premature or excessive interventions, reduces material consumption and construction waste and extends the service life of the infrastructure.

Since TSD measurements are carried out at traffic speed, no traffic management is required. Together with fewer maintenance interventions, this leads to less congestion and fewer traffic-induced emissions throughout the road's lifecycle.

In summary, the TSD enables a shift from reactive to performance-based strategic asset management. This study illustrates how structural diagnostics can address the root causes of emissions and resource inefficiencies, thereby laying the foundation for climate-resilient and resource-efficient road infrastructure systems.

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Track Classification: Materials Flow: Life-Cycle Analysis

Contribution ID: **43** Type: **Abstract TEC2ZERO**

Sustainable Energy Solutions for IoT: Low-Temperature, Low-Cost Thin-Film Organic Solar Cells

As the number of sensors and devices in the Internet of Things (IoT) grows, the demand for a reliable and sustainable energy supply becomes increasingly critical. Energy supply is particularly challenging in remote applications and/or in cases of poor accessibility. For these applications, batteries are unfavourable as they would have to be dimensioned for single-use discharge, making them bulky and expensive. Solar cells offer are better alternative as they can harness ambient light. However, the large ecological footprint of conventional solar cells presents a significant drawback in terms of sustainability as the production of silicon requires high temperatures (>~1400~°C) and significant amounts of material (750 g/m²). Therefore, thin-film solar cells made from perovskite or organic materials offer an ideal alternative to address these challenges. They make use of less material (approximately 0.8~g/m^2) which can be synthesized at low temperatures (<~120~°C) from abundant materials. Additionally, the substrate can be flexible and thin, allowing for a broader range of applications.

In our EU-funded project FOXES, we developed monolithic organic solar cell modules providing USB bus voltage (5~V) already under low level indoor lighting conditions (400~lux). Furthermore, our publications demonstrated that thin-film encapsulation preserved stability at over 90~% of the initial efficiency for more than 1000~h under elevated aging conditions (70~°C, 70~%~R.H.). These results indicate robust durability under harsh environmental stress, meeting key reliability benchmarks typically required for pre-qualification in industrial applications. Therefore, these cells are strong candidates for industrial-scale production.
In addition, thin-film solar cells offer notable economic and ecological benefits through energy-efficient recycling. Organic solvents can be kept in closed process cycles, and precious metal electrodes of the solar cell can be recovered by filtering and drying, enabling sustainable reuse.

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Track Classification: Future Technologies: Energy Efficiency

Contribution ID: **44** Type: **Abstract TEC2ZERO**

Port-Hamiltonian Surrogate Modeling for Renewable Energy Systems

The increasing complexity of energy system models necessitates the use of surrogate models for efficient computation of optimal operations. In recent years, physics-based surrogate modeling has gained significant attention for its ability to enhance the accuracy of these surrogate models. However, applying surrogate modeling to complex networks introduces the challenge of system decomposition.
When reassembling the system after surrogate models have been identified, the resulting interconnected model may lose critical system-theoretic properties such as stability or passivity.

We utilize the port-Hamiltonian (pH) framework, which facilitates physics-based modeling and maintains structural interconnections. The pH approach is demonstrated in the context of sector-coupled energy systems, where the pH modeling approach is demonstrated for electricity, heat, and gas grids. We show how submodels of the components such as transmission pipes, storages or heat pumps can be identified from high-fidelity simulation data. These identified pH models are then integrated into a comprehensive pH system model, facilitating optimization of the overall operation of the system. Finally, we present a comparative analysis of the optimization outcomes for both the surrogate model and the high-fidelity model, evaluating their performance in terms of accuracy and computational efficiency.

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Track Classification: Future Technologies: Energy Efficiency

Contribution ID: **45** Type: **Abstract TEC2ZERO**

Perovskite and Organic Solar Cells to Overcome the Green Paradox

Climate change presents unprecedented global challenges, urging a rethink of how resources, particularly energy, are harvested. Renewable energies like photovoltaics (PV) are probably the most sustainable energy sources, relying on the sun's free energy. However, PV remains underutilized, especially in developing countries, where infrastructure costs and maintenance pose significant barriers. Additionally, fossil fuels remain often more affordable and flexible, exacerbated by the "green paradox" - as decarbonization progresses, the reduced demand for fossil fuels may cause their prices to fall.
To remain competitive, renewable energy technologies like solar cells must continue to become cheaper and more adaptable. Unfortunately, silicon solar cells have nearly reached their efficiency and production limits, which underscores the critical need for a next generation of solar cells.
At the Institute of Electronic Devices, we are devoted to developing advanced thin-film solar cell technologies using organic or perovskite materials, that we believe to provide an avenue of breaking the green paradox. Both technologies require minimal energy and can be processed using cost-effective printing techniques from abundant materials, whilst offering efficiencies competitive with silicon. As thin-film devices they can also readily be integrated into buildings, vehicles, and other applications like IoT and satellites, able to transform the landscape of solar energy.
For the vision of affordable solar power from perovskite or organic solar cells to become a reality, several roadblocks have to be overcome. Most prominently a solid understanding of the processing routes and an enhancement of the long-term device stability are challenges that we tackle in several projects spanning from fundamental to industry-oriented research. Here I will present recent breakthroughs in our chair with internal barriers and process design, that have led to significant improvements in both stability and efficiency, bringing us step by step closer to an actual industry viable perovskite-organic PV technology.

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Track Classification: Future Technologies: Energy Efficiency

Contribution ID: **46** Type: **Abstract TEC2ZERO**

Psychology of Transformation: How Personality and Motivation Shape Sustainable Behavior and Business Processes

The current challenges of societal transformation into socially fair and ecologically sustainable economies require a deeper understanding of how people can be motivated, supported and empowered to change their habits and engage in sustainable behavior over longer time periods. In the present paper, we elaborate on the Personality-System-Interaction Theory as an integrative theoretical framework in psychological research, which differentially explains how, when, and why people are able and willing to support sustainable transformation and engage in environmentally compatible behavior. On the basis of this framework, we provide insights into three current projects, which aim at facilitating ecologically sustainable processes by creating best-possible psychological preconditions. First, the project "bergisch.kompetenz"seeks to develop and transfer in-depth expertise of solutions of circular economy into companies via human-resource processes (e.g., personnel and organizational development). In this project, we conceptualize different methods and instruments (based on the Personality-System-Interaction Theory), which enable and empower employees and experts to create and monitor sustainable material circles across different companies. Second, we also demonstrate another transdisciplinary project "Fit4Klima", which aims at developing and distributing a web- and APP-based software that fosters a sustainable and healthy behavioral lifestyle in different private domains (e.g., nutrition, sport activities, vacation, mobility etc.). Third, we will show and discuss findings from a longitudinal study on the relationships between individual attitudes, motivational tendencies, perceived political initiatives of sustainable transformation and sustainable behavior (foot-print). In doing so, we provide insights into promising precursors of sustainable behavior under different psychologically and politically relevant boundary conditions.

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Track Classification: Economy, Management and Education: Lifelong Learning

Contribution ID: **47** Type: **Abstract TEC2ZERO**

A Review on Enabling Waste and Carbon Reduction with Battery Management Systems for Second-Life Batteries

Abstract

The rapid rise of electric vehicles has sparked a parallel challenge: the sustainable management of end-of-life lithium-ion batteries. While no longer suitable for automotive applications, these batteries often retain a considerable amount of usable capacity, making them strong candidates for second-life deployment in stationary energy storage systems. As the world advances toward circular economy models and low-carbon energy systems, repurposing electric vehicle batteries offers a strategic solution to reduce both electronic waste and lifecycle greenhouse gas emissions. However, second-life batteries face inherent challenges chiefly aging, uneven degradation, and variable state-of-health that threaten their safety, performance, and reliability. In this context, battery management systems emerge as critical enablers for successful second life batteries integration. Intelligent battery management system technologies can continuously monitor battery health, detect faults, optimize energy throughput, and adapt system control to extend battery lifespan and improve performance.

This review presents a comprehensive examination of recent advancements in battery management system technologies specifically designed for second-life battery applications. Key areas include state of health estimation, fault diagnostics, adaptive control algorithms, and battery management system integration with renewable energy sources. The paper analyzes the impact of battery management system on system-level metrics such as reliability, degradation rate, and environmental performance, with studies indicating notable gains in battery longevity and emission reductions. Future research directions are identified in artificial intelligence based health prediction, modular battery management system architectures, and real-time diagnostics. Overall, this review underscores the essential role of battery management system in enabling scalable, efficient, and sustainable second-life battery systems. By addressing technical barriers and improving lifecycle management, battery management system technologies unlock the full environmental and economic potential of second life battery in modern energy infrastructures.

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Track Classification: Future Technologies: Energy Efficiency