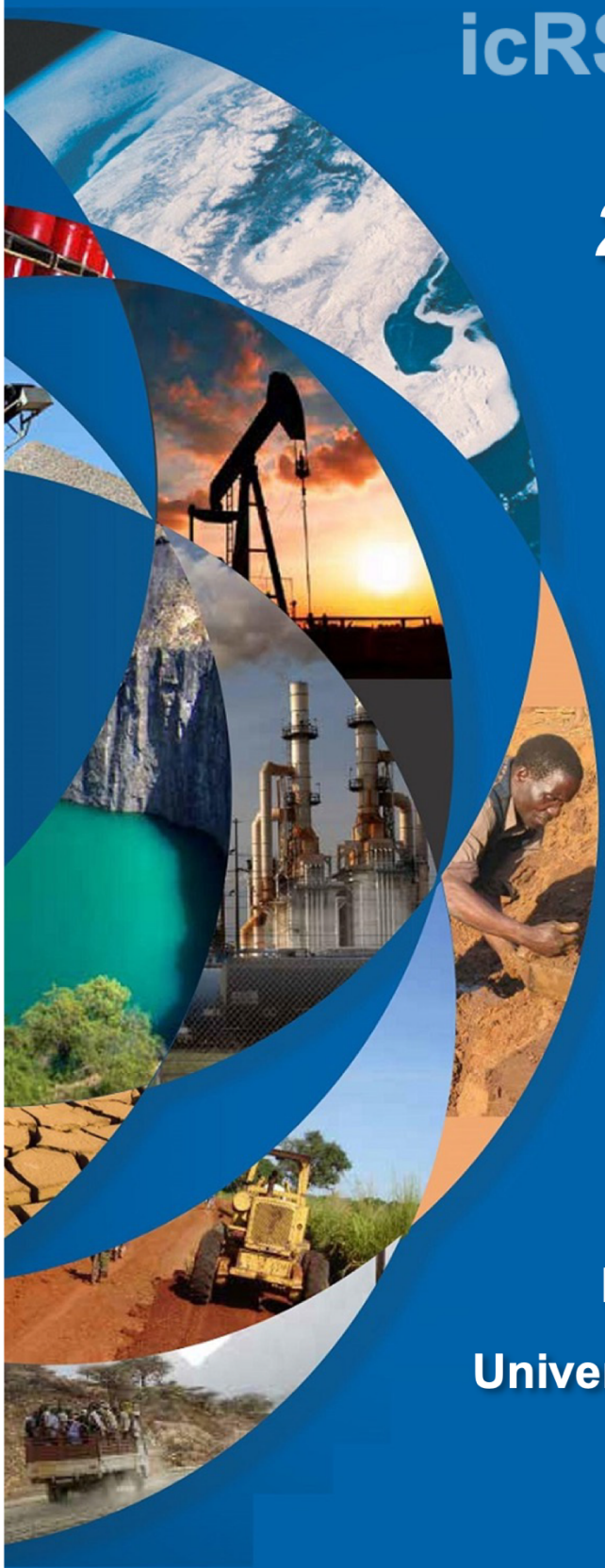
icRS 2026

2026 International Conference on Resource Sustainability



June 15-17, 2026

Cebu, Philippines

www.icrsconf.com

De La Salle University

University of San Jose-Recoletos

2026 International Conference on Resource Sustainability

(icRS 2026)

Welcome to icRS 2026!

The sustainable development of human society depends on resources. Addressing critical societal challenges, such as climate change, resource depletion, and environmental protection, requires sustainable management of resources using interdisciplinary approaches.

The **International Conference on Resource Sustainability (icRS)** series serves as an international platform for researchers and practitioners around the world with diverse backgrounds and expertise to share the most recent ideas, outcomes, and practices on resource sustainability.

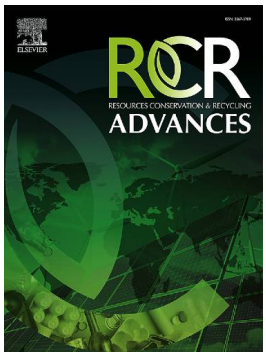
icRS embraces interdisciplinarity, welcoming contributions from ANY discipline, including natural sciences, social sciences, and engineering, on ANY aspect of resource sustainability. We define resource broadly, including physical resources, biological resources, and "misplaced" resources:

- physical resources: metals, non-metallic minerals, energy, water, etc.
- biological resources: food, forestry, land, ecological systems, etc.
- "misplaced" resources: air emissions, water pollutants, solid waste, etc.

icRS 2026, **co-hosted by De La Salle University and University of San Jose-Recoletos**, will include invited keynote speeches and parallel sessions,on a variety of topics related to resource sustainability.

icRS 2026 is sponsored by the flagship journal in sustainable resources management Resources, Conservation & Recycling (RCR; 2024 Impact Factor: 10.9) and its sister journal Resources, Conservation & Recycling Advances (RCRADV; 2024 Impact Factor: 6.4). High quality papers presented at icRS 2026 will be recommended to special issues in these journals as well as other supporting journals.

We are looking forward to meeting you.



Prof. Ming Xu

icRS Conference General Chair

Paper ID: 103

Are current circularity indicators fit for bio-based products? A critical test of MCI and ISO 59020.

Cristian Pérez-Hernández, Pieter Nachtergaele, Sophie Huysveld, Jo Dewulf

Ghent University, Belgium;

Email: cristian.perezhernandez@ugent.be

Abstract:

The circular bioeconomy combines principles from the circular economy and the bio-based economy to reduce fossil resource dependence and close material loops. However, current approaches to assessing circularity in bio-based product systems remain limited, as existing indicators do not fully capture the behaviour of bio-based resource flows. This contribution critically examines how two widely used approaches perform in this context: the Material Circularity Indicator (MCI) and the ISO 59020 set of circularity indicators. Their applicability and limitations are analysed for two contrasting bio-based products: wood-based chipboard panels and mycelium-based packaging, which differ in growth rate of the biomass and expected service life.

The analysis shows that both approaches only partially capture cascading performance and often fail to distinguish long, high-value use cascades from short, low-value applications. Bio-specific dynamics relevant for circularity, such as regrowth time or sustainable sourcing are narrowly represented or handled outside the indicators. Neither framework provides clear guidance on how to treat moisture content, so calculations are not consistently expressed on a dry-mass basis, which can distort comparisons across processes and life cycle stages. In addition, data requirements and allocation rules are not always aligned with the process realities of bio-based product systems, which can lead to ambiguous or misleading interpretations.

Building on these findings, we propose a holistic framework for circularity assessment of bio-based products that reflects the life cycle structure. It distinguishes a pre-use region, where circular inputs and cascading performance of primary inputs should be characterised; a use phase, where utility and in-use retention of material and function are captured; and a post-use phase, where circular outputs and cascading performance of secondary materials should be traced. This structured framework aims to guide the development and application of circularity indicators that are better aligned with the specific properties and dynamics of bio-based product systems.

Paper ID: 106

Future demand and potential risks of lithium for approaching China's carbon neutrality target

Jian-yu Wu [1,2,3,4,5], Biying Yu[1,2,3,4,5], Yi-Ming Wei[1,2,3,4,5]

[1]Center for Energy and Environment Policy Research; [2]School of Management, Beijing Institute of Technology; [3]Basic Science Center for Energy and Climate Change; [4]Beijing Key Lab of Energy Economics and Environmental Management; [5]Beijing Laboratory for System Engineering of Carbon Neutrality;
Email: jywoo@bit.edu.cn

Abstract:

Lithium is a critical material for batteries, glass, ceramics, and other products. The acceleration of the global low-carbon transition will drive an unprecedented surge in lithium demand, posing shortage risks. Thus, it is urgent to forecast future lithium demand and identify potential supply challenges to ensure the economic stability and decarbonization goals. Existing studies mainly focus on the automotive industry, failing to cover the entire demand. They are also limited in describing the differentiated driving forces for lithium demand change in different end-use industries. Therefore, this study developed China's Climate Change Integrated Assessment Model (C3IAM/NET), machine learning, and statistical models to forecast lithium demand by differing end-uses for low-carbon and traditional technologies. Taking China as the empirical context, results show that lithium demand will continue to grow rapidly under the impetus of China's carbon neutrality goal. Lithium demand is expected to peak at 2.5 million tons in 2035, representing a 206% increase from 2024. Current Chinese mines supply only 25% of demand, while by 2035 domestic production could only cover 8%. Low-carbon technologies will be the main driver of consumption, reaching over 1.85 million tons by 2035, with a compound annual growth rate of 10% between 2025-2035.Conversely, traditional industries show limited growth, except air treatment and pharmaceutical (CAGR 14%). Recycling measures and new mining projects could effectively increase the resource assurance, enabling supply to cover 80% of demand by 2035. Balancing industrial development and resource supply, along with mining expansion and recycling systems, will be essential to reduce shortage risks.

Paper ID: 111

Marine plastic debris and changing perceptions of natural and farmed seafood

Takaaki Kato[1], Aiko Endo[2]
[1]The University of Kitakyushu, Japan; [2]Nagasaki University, Japan;
Email: tkato@kitakyu-u.ac.jp

Abstract:

Increasing marine plastic debris is becoming a global issue. Psychological studies have shown that people have a common preference for natural food and products over artificially produced ones. This applies to seafood as well. However, heightened concern about marine plastic debris may change consumers' preferences. An online survey of 2000 adult citizens in Japan was conducted in December 2025. The sample was drawn from an online survey company's registered members and adjusted to match the country's gender and age group shares.

Among the provided options for critical problems in the ocean around Japan, 67% selected plastic debris pollution, outnumbering other problems such as water temperature and sea current changes (47.2%) and pollution by other debris (40.5%) in this multiple-choice question. This is a common tendency, as shown by the authors' surveys conducted in 2024 and early 2025 in the western part of the country, and it indicates great concern among Japanese consumers about the marine plastic debris issue.

The question about the perceptions of three sources of seafood provided curious results. On average, respondents valued the taste of natural seafood (39.2% strongly agreed) more than that of farmed seafood produced either in the sea or in a land-based aquaculture facility (20.2% and 13.4%, respectively). However, they thought that the seafood caught in the sea was more likely to contain microplastic debris (23.0% strongly agreed) than the marine-based (11.2%) and land-based aquaculture (3.4%).

A choice experiment framework was used to elicit respondents' willingness to pay for plastic-debris-free salmon. They valued wild salmon higher than farmed ones when other conditions were held equal. However, the value of plastic-debris-free farmed salmon outweighed that of wild salmon without information on plastic-debris content.

Paper ID: 113

Interprovincial timber carbon stock flows in China: spatial reconfiguration and forest carbon sink pressure assessment toward carbon neutrality

Chang Yu, Qiong Wu
Beijing Forestry University;
Email: changyu@bjfu.edu.cn

Abstract:

As China advances its national agenda for carbon neutrality and ecological civilization, understanding the dynamics of interprovincial timber carbon stock flows has become essential for evaluating forest ecosystem performance and allocating regional carbon sink responsibilities. Based on data from 30 provincial-level administrative regions from 2002 to 2017, this study constructs a timber carbon stock satellite matrix and employs a multi-regional input-output model (MRIO) to track interprovincial flows. Additionally, the Forestry Carbon Sink Pressure Index (FCSPI) is established to evaluate the alignment between consumption and local ecological capacity. The results show that the overall scale of timber carbon stock flows expanded significantly, accompanied by a distinct north-to-south spatial shift driven by forestry policies and industrial agglomeration. Traditional timber-producing regions such as the Northeast and Inner Mongolia experienced a decline in carbon stock outflows, while Guangxi, Guangdong, and Yunnan in southern and southwestern China have emerged as new composite flow centers supported by fast-growing plantation bases and processing clusters. Central and eastern provinces, by contrast, have become major inflow areas, assuming roles in consumption and adjustment. The FCSPI analysis reveals a pronounced spatial heterogeneity. Provinces in the Bohai Rim and central-eastern regions have timber carbon stock consumption levels exceeding their local carbon sink capacities, while the southwestern and northeastern provinces serve as net ecological suppliers. These findings illustrate the coupling mechanisms between timber use, forest ecosystem functions, and regional economic development. This study innovatively links MRIO-based accounting of timber carbon flows with a pressure-oriented evaluation of provincial sink capacity. The combined analysis helps clarify interprovincial ecological responsibilities and supports more coordinated and sustainable use of timber resources under China’s carbon neutrality goals.

Paper ID: 114

Identifying nonlinear links between forestry ecosystem services and green productivity using interpretable machine learning and scenario projections: evidence from four urban agglomerations in China

Qiong Wu, Chang Yu
Beijing Forestry University, China, People's Republic of;
Email: wuqiong24@bjfu.edu.cn

Abstract:

Forestry ecosystems are foundational to ecological security and green development. Under the "Dual Carbon" strategy, identifying the equilibrium between ecological value and green efficiency in urban agglomerations—key units for governance and technology diffusion—is critical. This study investigates 79 cities across four major Chinese urban agglomerations. An analytical framework integrating ensemble learning algorithms, interpretability analysis, and scenario simulation was constructed. Specifically, the study based on key factors selected via LASSO, optimal overall and regional machine learning models were established. Furthermore, SHAP (SHapley Additive exPlanations) was utilized to reveal the direction of marginal contributions and the interaction intensity of driving factors. Results show: (1) From 2000 to 2023, FESV was stable in southern coastal areas but grew in northern inland regions, with regulating services dominating the functional structure. (2) FTFP followed a U-shaped trajectory. Notably, resource endowment was not synchronous with green efficiency improvements, revealing structural constraints of high resources but low efficiency in specific regions. (3) Interpretable machine learning confirms strong nonlinearity and spatial heterogeneity: windbreak and sand fixation is the leading driver of FTFP in the pooled analysis, underscoring the role of ecological resilience in green productivity formation. Mechanisms differ by region: Beijing-Tianjin-Hebei is mainly driven by factor inputs and baseline ecological conditions; Chengdu-Chongqing is highly sensitive to grassland provision with insufficient multifunctional synergy; the Yangtze River Delta shows a high efficiency steady state supported by windbreak and sand fixation; and the Pearl River Delta is shaped by synergistic effects among multiple ecosystem services. (4) Future projections indicate fluctuating upward trends for both indicators. The highest synergy occurs under low-emission pathways (SSP-RCP1-2.6), while high-emission scenarios (SSP-RCP5-8.5) exacerbate climate risks and inhibit efficiency gains. This study reveals the spatiotemporal evolution of eco-efficiency, providing valuable references for ecological product value conversion and eco-economic integration.

Paper ID: 116

Evaluating global methane mitigation policies: A multi-source break-point analysis

Yating Xu, Meiyu Guo

Hong Kong Baptist University, Hong Kong S.A.R. (China);

Email: meiyuguo@hkbu.edu.hk

Abstract:

Methane, with its high global warming potential and short atmospheric lifetime, represents a critical target for climate mitigation, yet the effectiveness of global reduction policies remains poorly understood due to fragmented research and methodological gaps. This study establishes a global methane policy evaluation framework centered on three core components: a systematically compiled database of methane-specific policies across 48 major emitting countries (2000–2023), multi-source methane data integrating inventory and satellite observations, and a novel analytical approach combining machine learning-based breakpoint detection with two-way fixed effects regression. Our analysis reveals that policy adoption has accelerated since 2014, yet exhibits strong regional disparities. Structural break detection identifies significant mismatches between policy implementation timelines and emission trends, suggesting delayed or inconsistent impacts. Crucially, regression results demonstrate that policy combinations exhibit significantly stronger emission reduction effects compared to isolated interventions, with mandatory policies showing promise.

Paper ID: 117

Sustainable end-of-life (EoL) management of solar photovoltaic (PV) waste in Kenya: Implications for circular economy transition

Marlen Kwamboka Mochoge, Akemi Ori, Reginald Longfor Nkweauseh
Sophia University, Tokyo, Japan;
Email: marlenmochoge@gmail.com

Abstract:

The rapid expansion of solar photovoltaic (PV) systems in Kenya is central to Kenya's low carbon energy transition but is expected to generate significant volumes of end-of-life (EoL) PV waste as early installations reach retirement. Currently, Kenya lacks PV specific EoL regulations and waste management systems remain largely informal, raising environmental concerns and limiting the recovery of valuable materials such a silver and silicon. This study evaluated the scale and techno-economic feasibility of sustainable PV waste management options to inform evidence-based policy development in Kenya.

Annual and cumulative PV waste generation from 2025 to 2050 is estimated using the Weibull distribution function on early loss and regular loss scenarios. A techno-economic assessment is conducted through Cost-Benefit Analysis of three EoL management scenarios: i) Partial recovery of aluminum and copper, ii) Glass-focused recycling, and iii) Full material recovery including silver and silicon. Capital and operational costs are adopted from international recycling benchmarks to the Kenyan context, while benefits are derived from values of recovered materials. In addition, interviews with key stakeholders and regulators are conducted to identify barriers and opportunities for PV waste recycling and to inform policy recommendations.

Preliminary results indicate that cumulative PV waste in Kenya is projected to exceed 100,000 tons by 2050, with waste generation accelerating after 2040. Scenarios i) and ii) are not economically feasible even at high diversion rates mainly due to low value of recovered materials. In contrast, Scenario iii) demonstrates strong economic performance, achieving a positive Net Present Value and Internal Rate of Return above 10% at 20% diversion rate, primarily driven by recovery of high-value materials like silver and silicon.

The finding highlights the importance of comprehensive material recovery to unlock economic potential of PV waste and target policy interventions to enable a circular economy transition in Kenya's solar energy sector.

Paper ID: 122

Pervasive dependency on energy transition minerals

Simon Gossmann[1], Thomas Wiedmann[1], Elizabeth Thurbon[2], Benjamin Tallis[3]
[1]School of Civil and Environmental Engineering, UNSW Sydney, Australia; [2]School of Social Sciences, UNSW Sydney, Australia; [3]Helsing Germany GmbH, Berlin, Germany;
Email: z5614385@ad.unsw.edu.au

Abstract:

Anthropogenic-induced climate change presents states around the world with an increasingly pressing need to undertake a comprehensive 'energy transition' to sustainable modes of energy generation. Simultaneously, growing 'systemic competition' between democracies and autocracies has pushed the former to reconsider their dependencies on the latter – particularly regarding the critical minerals required for the energy transition (energy transition minerals or ETMs). Yet new trade dependencies for ETMs appear unavoidable given disparities in the locations of demand and supply.

Prevailing policy narratives argue that depending on autocracies to supply ETMs creates a conflict between the imperatives of the energy transition and systemic competition. Policy-makers are therefore working to mitigate the impacts of ETM-trade dependencies. However, the threshold question of whether ETM trade dependencies will be similar to, or different from, dependencies which exist for supply of fossil fuels has not been adequately addressed. Further investigation is therefore required to evaluate whether ETM trade offers the same potential for exploitation, via economic coercion, as historic dependencies for fossil fuels.

To do this, this project has, for the first time, quantified the 'pervasive dependency' of democracies on suppliers of the ETMs cobalt, copper and nickel. We define pervasive dependency as the extent to which a particular economy 'consumes' embodied ETMs used anywhere along the entire supply chain, not just those physically exported to the consuming location. Pervasive dependency was calculated from consumption-based accounts using an ETM-trade-enhanced version of the GLORIA multi-region input-output table. The pervasive dependency for an economy i.e., final consumption, split by sector, is presented along with the region of origin of the ETMs. This study provides a quantitative evaluation of how dominant paradigms regarding strategic risks may be affected by future ETM-trade dependency. It also enables subsequent analysis of whether trade-decoupling and recreating supply chains might unnecessarily delay the energy transition.

Paper ID: 123

Evidence-based land use planning for climate change: A multi-hazard risk assessment approach

Chih Chao Ho[1], Jian-Cheng Liao[1], Chung-Huai Hsu[2], Yung-Ching Hsu[3]
[1]Construction and Disaster-Prevention Research Center, Feng Chia University, Taiwan; [2]Program in Landscape & Recreation, National Chung Hsing University Taiwan; [3]Department of Urban Planning and Spatial Information, Feng Chia University, Taiwan;
Email: zz0813@gmail.com

Abstract:

Integrating multi-hazard risk assessment into spatial planning is critical for enhancing national resilience. Based on the quantitative framework of "Hazard × Vulnerability × Exposure," this study conducts a national-scale assessment for flood, landslide, drought, and heatwave under current and future scenarios. The objective is to identify high-risk areas and adaptation gaps to serve as a scientific basis for climate change adaptation strategies in the next National Adaptation Plan and the National Spatial Plan.

The results reveal significant spatiotemporal heterogeneity in risk distribution: (1) Flood risks are concentrated along the Lanyang and Gaoping River basins with an expanding coastal trend; (2) Landslide risks remain localized in the mountainous regions of central, southern, and eastern Taiwan, showing limited spatial shift under climate change; (3) Drought risks, under the GWL 2.0°C scenario with projected water demand growth, are predicted to expand northward from the southwestern plains to the northern metropolitan areas; and (4) Heatwave risks show the most dramatic escalation, evolving from low current risk to covering major cities in central and southern Taiwan in the near term (GWL 1.5°C), and encompassing all major western and eastern cities in the medium term (GWL 2.0°C).

Drawing on these findings, this study proposes 22 strategies for the upcoming National Adaptation Plan (2027–2030), emphasizing the reduction of vulnerability through groundwater conservation and the limitation of exposure through development controls.

Paper ID: 126

A critical review for Life Cycle Assessment of packaging with plastics and alternative materials in the Asia-Pacific region

Jiayi Yuan[1], Huimin Chang[1], Weiqian Zhang[2], Experience Nduagu[3], Richa Kirti[3], Timothee Roux[4], Nan Li[1], Ming Xu[1]

[1]Tsinghua University, Beijing, 100084, China, People's Republic of; [2]ExxonMobil Asia Pacific Research & Development Co., Ltd, Shanghai, China, People's Republic of; [3]ExxonMobil Technology and Engineering Company, 22777 Springwoods Village Pkwy, Spring, TX 77389, USA; 4Exxon Mobil Corporation, 22777 Springwoods Village Pkwy Spring, TX 77389, USA;

Email: yuanjy24@mails.tsinghua.edu.cn

Abstract:

Asia-Pacific (AP) economies are experiencing a rapid increase in packaging consumption driven by economic growth, urbanization, and evolving lifestyles, while at the same time many consider the potential environmental impacts of packaging. This creates a growing tension between enabling packaging functions and reducing. Life cycle assessment (LCA) can be used to inform packaging policy and design, yet conclusions about the environmental impacts of plastics and their alternatives are often inconsistent and even contradictory. This review synthesizes LCA studies on plastic packaging and alternative materials in the AP region, including paper and cardboard, metal, glass, and bio-based and degradable plastics. We screened the literature from roughly the past decade and extracted 176 material comparisons from qualifying studies. We mapped commonly studied packaging formats and end-use applications, and compared reported global warming potential (GWP) across different materials and contexts. Our analysis found that the performance of packaging strongly depends on background conditions such as energy mix, recycling rates, waste management options, and production burdens. Moreover, cross-study comparability is constrained not only by methodological heterogeneity, such as divergent functional unit definitions, system boundaries, and allocation choices, but also by insufficient localization and transparency of life cycle inventory (LCI) data for many AP economies. These issues can obscure environmental trade-offs between materials and leave decision-makers without actionable insights. Building on these findings, we propose a consistent LCA modeling approach for packaging in the AP and outline priorities for future research. Key directions include developing regionally representative LCI datasets, harmonizing methodological choices to improve comparability, and strengthening scenario analysis that accounts for transport, use, and end-of-life pathways. These steps can enhance the robustness and policy relevance of packaging LCA in AP economies by supporting the design of context-appropriate packaging decisions aimed at reducing environmental impacts rather than one-size-fits-all solutions such as blanket plastic bans.

Paper ID: 127

Strategic optimization and comparative evaluation of hybrid recycling modes for retired photovoltaic modules: A Stackelberg game approach

Duan Zhen, Li Jing
School of Economics and Management, Taiyuan University of Technology, Taiyuan 030024, Shanxi, China;
Email: duanzhen0298@link.tyut.edu.cn

Abstract:

With the rapid expansion of global photovoltaic (PV) installations, the PV industry faces significant challenges arising from the impending wave of retired modules. Establishing a multi-stakeholder collaborative hybrid recycling system is critical for the effective management of retired PV products. Employing Stackelberg game theory, this study constructs decision models for three hybrid recycling modes: Manufacturer-Distributor (MD), Manufacturer-Third Party (MT), and Distributor-Third Party (DT). Subsequently, backward induction is applied to derive the optimal pricing and collection strategies for each stakeholder. Results reveal that: (1) The choice of recycling mode exerts no influence on the wholesale and selling prices of new products in the forward supply chain. However, lenient carbon quota policies and tax incentives effectively reduce forward supply chain pricing while boosting collection quantities. (2) Across all modes, higher echelon utilization rates and carbon trading prices suppress collection quantities due to resource diversion and cost constraints. (3) Manufacturer collection prices are positively driven by subsidies, whereas distributor and third-party prices in the DT mode are consistently lower than those in MD or MT modes. (4) Manufacturer-led modes (MD/MT) generally outperform the DT mode in collection volume, with their relative superiority contingent on logistics distance. Accordingly, this study offers valuable theoretical insights and strategic guidance for stakeholders aiming to develop an efficient and sustainable PV recycling system.

Paper ID: 129

Global crop and associated nutrition risks from unsustainable water use and trade

Chenglong Wang[1], Chenyang Shuai[1], Xi Chen[2]
[1]School of Management Science and Real Estate, Chongqing University, Chongqing, China; [2]College of Economics and Management, Southwest University, Chongqing, China;
Email: chenglongwang@stu.cqu.edu.cn

Abstract:

Water is fundamental to agricultural production and nutrition security, yet many regions sustain crop production by withdrawing water beyond environmentally sustainable limits. While this practice maintains short-term yields, it may undermine long-term productivity. Here we assess global crop production risks from unsustainable water use at the sub-basin level, trace their propagation through international trade, and quantify associated nutrition impacts. We find that unsustainable water use threatens 45% (23–59%) of irrigated crop production in 2020, with hotspots in the western and central United States, northern China, and the Indo-Gangetic Plain. About 13% (11–20%) of local production risk is transmitted internationally through trade, largely originating from high-income countries. Overall, 21% (11–28%) of the global population faces nutrition risks linked to unsustainable water use, with the greatest impacts in middle-income countries.

Paper ID: 130

Understanding rural-driven water scarcity in China: spatiotemporal dynamics and drivers to sustainable water management

Yaqi Yang[1], Xi Chen[1], Chenyang Shuai[2]

[1]SouthwestUniversity, China, People's Republic of; [2]ChongqingUniversity, China, People's Republic of;

Email: 3551464816@qq.com

Abstract:

Water scarcity threatens the sustainability of global socio-economic and ecological systems, with China facing particularly severe pressure. While urban water challenges have received wide attention, the role of rural residents—who account for a large share of China's population and whose consumption patterns strongly influence water use-remains underexplored. Addressing this gap, this study assesses the extent of rural consumption-driven water scarcity and its underlying drivers across regional and sectoral scales. We integrate a multi-regional input–output model with a potential water scarcity index for evaluating rural-driven water scarcity in 313 administrative units of 42 sectors in China from 2012 to 2020, and apply structural decomposition analysis for identifying the key driving factors. Results show that rural-driven water scarcity fluctuated but declined overall. At the national level, production efficiency gains, technological advancement, and structural optimization alleviated water scarcity in most years. At the administrative level, these drivers displayed heterogeneous effects due to local characteristics. At the sectoral level, the number of industries with rising scarcity decreased, with technological progress emerging as the main mitigating force. Our findings underscore the crucial role of rural consumption in shaping China's water future and highlight the importance of integrating rural consumption into sustainable water management strategies to accelerate progress toward SDG 6.

Paper ID: 132

Mapping the spatiotemporal evolution of global agricultural sustainability footprints

Lu Wang[1], Xi Chen[1], Chenyang Shuai[2]
[1]SouthwestUniversity, China, People's Republic of; [2]ChongqingUniversity, China, People's Republic of;
Email: 13896710377@163.com

Abstract:

Agriculture is a key sector characterized by intensive resource use and environmental pressure, and its production and consumption exert profound environmental, social, and economic impacts along global supply chains. However, existing assessments largely focus on the agricultural production side and neglect the indirect effects transmitted through supply chains across regions and industries driven by final demand. To address this gap, this study employs a multi-regional input–output (MRIO) model to comprehensively assess agriculture-related sustainability footprints at the global scale from 1990 to 2021, and develops a multi-layered framework of comprehensive sustainability footprints. The results show that the global comprehensive sustainability footprint of agriculture exhibits a persistent downward trend, indicating a continuous weakening of overall sustainability performance. From a structural perspective, while the comprehensive sustainability footprint declines, the relative weight of the economic dimension increases; this change mainly reflects structural adjustments driven by declines in the positive contributions of environmental and social dimensions, rather than improvements in economic performance, and therefore fails to support an overall enhancement of sustainability. In addition, the distribution of agricultural sustainability performance across countries is highly uneven, with countries exhibiting higher sustainability levels primarily concentrated in North America, Europe, and East Asia, which transmit relatively higher sustainability performance to other countries through international trade. Moreover, sustainability footprints induced by agricultural activities are not confined to the agricultural sector itself, but are widely distributed across upstream sectors such as energy, manufacturing, chemicals, and services. These findings deepen the understanding of the sustainability performance of global agricultural activities and provide scientific evidence for improving agricultural sustainability, optimizing trade structures, and promoting cross-regional cooperation.

Paper ID: 133

Co-located renewable hydrogen micro-grids for hard-to-abate sectors in China: Integrating demand, supply and infrastructure

Maximilian Arras[1,2], Niels Jakerson[1,3], Josin Hu[1,2], Linwei Ma[1,2]
[1]Tsinghua-Rio Tinto Joint Research Centre for Resources, Energy and Sustainable Development, Laboratory for Low Carbon Energy, Tsinghua University, Beijing, China; [2]State Key Laboratory of Power Systems, Department of Energy and Power Engineering, Tsinghua University, Beijing, China; [3]RWTH Aachen University, Templergraben 55, Aachen, 52062, Germany;
Email: lian21@mails.tsinghua.edu.cn

Abstract:

Recurring concerns over energy crises and oil-market volatility highlight the need to decouple hard-to-abate sectors from fossil fuels and traded energy carriers. This study examines how renewable hydrogen can support industrial decarbonization and energy security in China by jointly modeling hydrogen demand, co-located supply, and transport infrastructure. An integrated framework combines geospatial demand mapping, techno-economic optimization of renewable hydrogen micro-grids, and stylized pipeline network analysis. Results show that China's potential hydrogen demand is strongly dominated by industrial applications, especially steel and chemicals, while aviation and maritime shipping form concentrated transport-related demand hubs. Current project patterns and policy direction suggest a development pathway centered on co-located renewable hydrogen micro-grids. Cost competitiveness depends mainly on geography, renewable resource quality, and operating regime, with wind-rich, high-utilization systems achieving the lowest levelized costs of around 24–25 CNY/kg. Pipeline expansion is best understood as a phased long-term option focused on dense industrial corridors.

Paper ID: 135

Consumer adoption of sustainable aviation fuels: A Theory of Planned Behavior perspective

Guada Altea Erin Layugan, James David Abiog, Mac Joseph Rosales, Jonna Baquillas, Kathleen Aviso
Center for Engineering and Sustainable Development Research, De La Salle University;
Email: guada.layugan@dlsu.edu.ph

Abstract:

The aviation industry significantly contributes to global warming, accounting for ~2% of global emissions, posing a threat to the environment. Utilizing sustainable aviation fuels (SAFs) is recognised as an important element in decarbonizing this hard-to-abate sector. Policies have been implemented to encourage airlines and countries to adopt SAF to achieve net-zero emissions by 2050. In order to address insufficient feedstock availability, policy inconsistencies, and high prices, studies have suggested international collaboration, research funding, and tax incentives to address the hindrances in SAF adoption. Studies have explored the role of public consumers as a contributing factor to the successful adoption of SAF. The Theory of Planned Behavior (TPB) is widely used to understand sustainable consumption behavior, however, research determining consumers' willingness to pay (WTP) under this framework remains lacking. This study aims to identify the psychological constructs influencing the willingness to pay of public consumers and their implications to SAF policies. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework is utilized for data identification and selection, while the TPB framework is utilized to extract and analyze psychological constructs influencing WTP. Social trust, carbon neutrality interest, public perception, cost concerns, and lack of information are found to influence WTP. The findings suggest airlines and policymakers include public awareness to bridge knowledge gaps and to help normalize the behavior.

Paper ID: 136

The double-edged effects of China Certified Emission Reduction (CCER): promoting overall innovation while crowding out green transformation

Chenlu Tao[1], Chang Yu[2]

[1]North China Electric Power University; [2]Beijing Forestry University;

Email: taochenlu@ncepu.edu.cn

Abstract:

The reactivation of the China Certified Emission Reductions (CCER) mechanism is a key policy development in China's carbon emissions reduction strategy. While much attention has been paid to carbon trading mechanisms and their impact on corporate behaviour, the specific effects of CCER's reactivation on green innovation in heavily polluting industries remain underexplored. This study aims to examine the influence of CCER reactivation on green innovation in heavily polluting enterprises, exploring how participation in the carbon emission trading market affects innovation dynamics, and identifying the mechanisms underlying these changes. The findings show that CCER suppresses green innovation in heavily polluting enterprises. While CCER integration into the carbon market enhances other forms of innovation and overall innovation improvement within these enterprises, it presents a notable drawback that CCER leads to a misinterpretation by some enterprises that purchasing carbon credits is a more cost-effective alternative to investing in green innovation. Consequently, certain enterprises have reduced their investments in green innovation in the short term. We contribute to the new insights into the unintended market signals that CCER may transmit to enterprises. Moreover, the negative impact of CCER on green innovation is more pronounced in state-owned enterprises compared to private firms. It also considers the impact of both CCER reactivation and its suspension, ensuring a robust analysis. The study offers valuable theoretical support and policy recommendations, including the establishment of a dynamic carbon quota allocation mechanism, to optimize the incentives for green innovation and sustainable development.

Paper ID: 137

Increasing energy system flexibility in China: Evolution of multi-regional power-to-methanol system from 2025 to 2060

Josin Hu[1,2], Maximilian Arras[1,2], Linwei Ma[1,2]

[1]Tsinghua-Rio Tinto Joint Research Centre for Resources, Energy and Sustainable Development, Laboratory for Low Carbon Energy, Tsinghua University, Beijing, China; [2]State Key Laboratory of Power Systems, Department of Energy and Power Engineering, Tsinghua University, Beijing, China;
Email: hu-zx25@mails.tsinghua.edu.cn

Abstract:

Under the dual carbon goals in China, low-carbon, but variable renewable electricity sources like solar and wind, is expected to increase. This is accompanied by issues of temporal and geographic variability, and maintaining energy security becomes a challenge under the low-carbon transition. Addressing this issue of decreasing supply-demand balance requires flexibility solutions, Power-to-Methanol has emerged as one option, chosen since methanol benefits from mature supporting transport and storage technology and existing downstream demand. The present research has therefore evaluated the use of power-to-methanol in the role of controllable demand; which consumed excess supply through cross-sectoral coupling. The methodology has used projected hourly load and supply data to quantify the imbalance in the electricity grid for the period of 2025 to 2060. The capacity of flexible power-to-methanol is based on the magnitude of this imbalance, and a fixed price for methanol sold in downstream markets is used for a techno-economic analysis of the solution. Finally, the robustness of the solution was assessed through a sensitivity analysis. Results show that energy supply imbalance has distinct regional characteristics, oversupply of variable renewable energy occurs in 2045 in western China, whereas in eastern China, demand is still met by firm dispatchable generation (such as thermal power) from 2025 up to 2060. A key relationship demonstrated is that variable resources and dispatchable generation are in competition; increasing penetration of renewables reduces the utilisation rate and installed capacity of dispatchable generation. Moreover, the economic feasibility of power-to-methanol greatly depends on its utilisation rate. At a low utilisation rate of <15%, the net present value of the system amounts to -1.4 trillion CNY, this improves to -0.3 trillion CNY, when utilisation rate is >60%. Utilisation rates, however, are influenced by curtailment rates. Energy security therefore requires the right blend of flexibility solutions to ensure an economic optimum.

Paper ID: 138

The impact of food financialization on international food security: A theoretical and empirical study based on the core-periphery world system

Qi He[1], Zihan Kang[1], Han Ji[2]
[1]University of International Business and Economics, Beijing 100029,China; [2]Agricultural Information Institute, Chinese Academy of Agricultural Sciences, Beijing 100081, China;
Email: qqleslie-32@163.com

Abstract:

The global food crises erupting in 2008 and 2022 have exposed deep-seated structural contradictions within the global food security system. Notably, these contradictions do not stem from insufficient global food production but rather from the drastic fluctuations in international food prices. Underpinning such price volatility are the failure of the price mechanism and the excessive intervention of financial factors, which manifests as the increasingly prominent phenomenon of "food financialization." This paper situates theoretical models of food financialization and food security within the imbalanced structure of the core–periphery world system. It argues that, under the contradiction between the profit-seeking nature of finance and the vulnerability of food, short-term growth in monetary wealth comes at the cost of food insecurity. By deriving theoretical results on the endogenous inequality of food financialization based on the Edgeworth box, this paper provides theoretical support for the abnormal fragility of the contemporary food system under conditions of food financialization. In particular, we construct a measurement index of food financialization from the perspective of the interaction between futures markets and spot markets, and designs a panel data model based on it. The results indicate that food financialization has a significant adverse effect on food security, with pronounced heterogeneity between core and peripheral countries. For core countries, the negative impact of food financialization on food security is significantly mitigated and may even turn positive; for peripheral countries, by contrast, the negative impact is further amplified. These findings are robust to alternative specifications. In addition, the moderating effect model shows that financial development significantly moderates this impact, while the mediation effect model indicates that food financialization leads to food insecurity by exacerbating food price volatility. The findings of this paper are conducive to providing effective policy implications for resolving global food security issues from the perspective of food financialization.

Paper ID: 139

Urban sprawl, functional centrality, and traffic externalities in Central Africa: The case of Yaoundé's satellite towns

Anehmbom Ghoutum[1], Nkweauseh Reginald Longfor[1], Aloysious Kohtem Lebga[2], John Joseph Puthenkalam[1], Xuepeng Qian[1]

[1]Graduate School of Global Environmental Studies, Sophia University, Japan; [2]National Institute of Cartography, Yaoundé, Cameroon;

Email: n-longfor-3r2@sophia.ac.jp

Abstract:

Rapid urban sprawl and strong functional centrality in African cities intensify commuting, congestion, and pollution, yet their combined impacts remain weakly quantified. This gap limits the design of integrated land-use and transport policies that can reduce congestion, emissions, and economic losses in fast-growing urban regions. This study examines how urban sprawl and functional centrality contribute to environmental pollution and congestion-related economic losses in three satellite towns (Soa, Mfou, Mbankomo) connected to the urban core of Yaoundé, Cameroon. We apply a quantitative approach using household, driver and traffic survey data, coupled with geospatial analysis and regression modelling, to estimate congestion patterns, missed trips, annual fuel use, tailpipe carbon dioxide emissions, travel mode choice, and driver revenue losses and passenger value of time (VOT). Results show pronounced temporal peaks, with average daily corridor congestion times of about 214 minutes in Soa, 204 minutes in Mbankomo, and 165 minutes in Mfou, equivalent to roughly 1,302, 1,240, and 1,003 annual hours of delay, respectively. Annual missed trips reach 2,920 in Soa, 1,825 in Mfou, and 2,555 in Mbankomo, causing revenue losses of 17.3, 6.0, and 6.2 million Central African CFA francs (≈28,800, 10,000, and 10,200 United States dollars), for a combined loss of 29.5 million CFA (≈49,000 USD). Weekly CO_2 emissions are highest in Soa (124,961 kg), followed by Mfou (39,954 kg) and Mbankomo (10,936 kg). Longer trip durations significantly increase the likelihood of using collective transport, while higher income and higher per-trip spending favour private cars, reinforcing car dependence among better-off groups. The study offers targeted policy measures—such as promoting polycentric development, relocating jobs and services nearer to satellite towns, and investing in reliable public transport and pricing instruments that internalise congestion and emission costs—to support integrated land-use–transport planning in rapidly growing African cities.

Paper ID: 140

Resource-efficient port-scale pathways for hydrogen-based maritime fuels in China

Niels Jakerson[1,2], Maximilian Arras[1,3], Linwei Ma[1,3]
[1]Tsinghua-Rio Tinto Joint Research Centre for Resources, Energy and Sustainable Development, Laboratory for Low Carbon Energy, Tsinghua University, Beijing, China; [2]RWTH Aachen University, Templergraben 55, Aachen, 52062, Germany; [3]State Key Laboratory of Power Systems, Department of Energy and Power Engineering, Tsinghua University, Beijing, China;
Email: nes25@mails.tsinghua.edu.cn

Abstract:

The global shipping sector emitted approximately 911 Mt CO2 in 2023, accounting for nearly 3% of global emissions, with China responsible for about 8.5% of shipping-related emissions worldwide. As a hard-to-abate sector, maritime decarbonization increasingly relies on hydrogen-based alternative fuels such as ammonia and methanol. However, their large-scale deployment requires substantial supplies of low-carbon electricity and places strong pressure on land availability and infrastructure at coastal ports. This study develops a port-resolved techno-economic framework to assess resource-efficient pathways for supplying hydrogen derivatives to China's coastal shipping sector. Building on an existing renewable energy system (RES) configuration that optimizes port-side microgrids combining photovoltaic power, wind generation, battery storage, and waterelectrolysis across 68 major Chinese ports, the framework is extended in three dimensions. First, nuclear electricity is introduced as a firm, carbon-free supply option to complement variable renewables and to alleviate land-use constraints in dense port–industrial environments. Second, the upstream power–hydrogen system is expanded to include detailed representations of green ammonia and e-methanol synthesis, incorporating electricity demand, operational constraints, and port-side storage to balance production and bunkering. Third, port-level fuel demand is modeled using two archetypes, activity-based projections and residual-carbon pathways, under scenarios of high and low cargo throughput and technology adoption. The integrated system is optimized at the port level to quantify changes in optimal capacity mix, dispatch behavior, curtailment, and storage requirements relative to RES-only configurations. Resulting hydrogen costs are benchmarked against prior estimates (4.3–11.6 USD/kg), while additional outputs include port-level fuel production costs, total investment requirements, land-use footprints, and CO2 mitigation potential across decarbonization trajectories through 2060. By jointly quantifying cost, flexibility, land use, and emissions trade-offs, this study provides a spatially explicit basis for evaluating hybrid energy systems as resource-efficient enablers of maritime decarbonization in China.

Paper ID: 141

Assessing progress towards a circular economy in sub-Saharan Africa: A comparative evaluation of municipal waste management systems in Cameroon and Ghana

Nkweauseh Reginald Longfor[1], Maria Tomai[2], Alessio Campitelli[3], Xuepeng Qian[1]
[1]Graduate School of Global Environmental Studies, Sophia University, Japan; [2]Virginia Polytechnic Institute and State University, Virginia, USA; [3]IWAR – Environmental Analytics and Pollutants, Technische Universität Darmstadt, Darmstadt, Germany.;
Email: n-longfor-3r2@sophia.ac.jp

Abstract:

Urban waste management systems in sub-Saharan Africa are under pressure from rapid urbanisation, limited infrastructure, and growing resource constraints, yet empirical evidence on their transition towards a circular economy (CE) remains scarce. This lack of systematic assessment constrains the design of effective policies and investments to accelerate CE transitions in the region. This paper evaluates and compares how Ghana and Cameroon, both members of the African Circular Economy Alliance, have progressed from linear to circular municipal waste management. We apply a mixed-methods approach that combines literature review, field surveys, and semi-structured stakeholder interviews, and we analyse these data using the Waste Management System Development Stage Concept (WMSDSC) framework. Seven components are assessed in each country: governance, sector and market, collection and transport, waste disposal, energy recovery, waste recycling, and prevention and reuse. The resulting waste system performance is classified on a five-stage scale: (1) essential elements absent or lacking, (2) reliable collection and improved landfill sites, (3) separate collection and sorting, (4) expanded recycling industry, and (5) circular economy with waste as a resource. Results show that governance structures in both countries lie mainly between stages 2 and 3, indicating emerging but weakly enforced frameworks. Sector and market development ranges from stages 1–3 in Cameroon and 2–4 in Ghana, with Ghana showing more advanced but uneven market readiness. Waste disposal is largely at stage 1 in Cameroon and stages 2–3 in Ghana, while waste recycling and energy recovery remain predominantly at stage 1 in both countries, with only a few Ghanaian subcomponents reaching stage 3 or partial stage 2. Furthermore, this study provides targeted policy recommendations for both countries, highlighting critical needs for regular regulatory updates, sustainable financing and incentives, awareness and skills development, capacity building, clearer institutional roles, stronger extended producer responsibility, and mandatory separation and collection of recyclables.

Paper ID: 145

Decarbonizing construction through circular supply chain 4.0: An interdependent practice system

Yeneneh Tamirat Negash
Asia University, Taiwan;
Email: yeneneh@asia.edu.tw

Abstract:

The construction sector's substantial contribution to global carbon emissions has intensified the need for decarbonization across construction supply chains. Circular Supply Chain 4.0 (CSC 4.0) integrates circular economy principles with Industry 4.0 technologies and is increasingly discussed as a route for decarbonizing construction. However, existing research commonly reports digital and circular interventions as standalone levers, which limits understanding of how decarbonization practices reinforce or enable one another in practice. This study conceptualizes decarbonizing construction through CSC 4.0 as an interdependent practice system and maps its hierarchy and influence structure. A content analysis identifies candidate practices, which are validated using the fuzzy Delphi method (FDM). Interpretive Structural Modeling (ISM) organizes the validated practices into hierarchical levels, and fuzzy decision-making trial and evaluation laboratory (FDEMATEL) maps the directional influence structure among aspects and practices. The results validate 26 practices grouped into five aspects: Smart Technology Integration, Circular Business Practices, Green Supply Chain Management, Operational Optimization, and Supply Chain Transparency. The influence analysis indicates that Smart Technology Integration, Circular Business Practices, and Green Supply Chain Management play net driving roles, while Operational Optimization and Supply Chain Transparency act as dependent outcome aspects. At the practice level, digital adoption, logistics efficiency, technology trend awareness, collaborative networks, competitiveness, organizational efficiency, and remanufacturing emerge as high-leverage drivers. The study provides a systems-based explanation of construction decarbonization under CSC 4.0 and offers practical guidance for sequencing and prioritizing interventions.

Paper ID: 150

Systems optimization of Hub-and-Spoke biomass-to-SAF for intra-island supply chains

James David Abiog, Guada Altea Erin Layugan, Mac Joseph Rosales, John Frederick Tapia, Andres Philip Mayol, Jayne Lois San Juan, Kathleen Aviso
Center for Engineering and Sustainable Development Research, De La Salle University, Philippines;
Email: james.abiog@dlsu.edu.ph

Abstract:

Commercializing Sustainable Aviation Fuel (SAF) in archipelagic regions faces a critical geographic barrier: high inter-island logistics costs. Centralized biorefineries often prove economically unviable due to the volumetric penalty of transporting low-density raw biomass. This study assesses the operational efficiency of a decentralized hub-and-spoke network to overcome these disruptions. The research utilizes a mixed-integer linear programming (MILP) model to design a framework tailored for solid agricultural crop residues in Misamis Oriental, a province in the island of Mindanao, Philippines, characterized by coastal and mountainous agricultural land. Strategically located depots perform initial densification prior to long-haul transit. Optimization results demonstrate that shifting to densified intermediates at the source reduces total network logistics operational expenditures to a mere 0.16% of the total annualized cost, even when accounting for the fixed capital expenditures (CAPEX) of the infrastructure. This confirms that decentralized densification effectively neutralizes the archipelagic geographic penalty, significantly improving SAF commercialization viability.

Paper ID: 151

Unlocking sludge co-firing synergies between thermal power and wastewater treatment plants

Jin Lin[1,2,3], Qi Zhou[1,2,3], Linyuan Hu[1], YuChen Hu[1,2,3], Yunlei She[1,2,3], Shen Qu[1,2,3]
[1]School of Management, Beijing Institute of Technology, Beijing 100084, China; [2]Center for Energy & Environmental Policy Research, Beijing Institute of Technology, Beijing 100084, China; [3]Beijing Laboratory for System Engineering of Carbon Neutrality, Beijing Institute of Technology, Beijing 100084, China;
Email: jinlin_d@outlook.com

Abstract:

Sludge from municipal wastewater treatment plants (MWWTPs) serves as an alternative fuel for co-firing in thermal-fired power plants (TFPPs), turning sludge disposal from a burden into a low-carbon opportunity. However, such symbiosis remains limited by the alignment of temporal-spatial sludge-fuel dynamics and economic feasibility. To address these challenges, we develop a monthly sludge allocation modelling framework at plant level that captures MWWTP-TFPP temporal and spatial interactions under economic and technological uncertainties. The framework is supported by a self-developed high-temporal resolution database, covering 5,218 MWWTPs and 1,990 TFPPs across China. Results show that excessive residual sludge from 3,684 MWWTPs (~66% capacity) instead facilitates monthly-consistent coal reductions for 422 qualified coal-fired power plants. Under current fuel price, such MWWTP-TFPP collaboration can reduce sludge by 75% (95% CI: 8-88%) and mitigate 14.53 (95% CI: 1.62–17.29) Mt CO_2eq annually – equivalent to 48% (5–58%) of national MWWTP emissions – yielding annual median profits of 147 million CNY. Raised fuel prices further increase these environmental and economic benefits by ~6% and 326%, respectively. Our framework supports cross-sectoral circular strategies and environmental policies tailored to regional and resource-specific needs for global sustainability.

Paper ID: 152

Evaluating the environmental and global supply chain impacts of port congestion

Yunlei She, Shen Qu
Beijing Institute of Technology, China, People's Republic of;
Email: yunlei.she@hotmail.com

Abstract:

Transportation network disruptions caused by geopolitical conflicts, pandemics, and climate extremes have exposed critical vulnerabilities in the global supply chain, with far-reaching consequences for both the environment and global economic security. However, modeling the environmental and supply-chain impacts at high temporal resolution across diverse industries and regions remains challenging, limiting our ability to effectively evaluate and design resilience measures. This study integrates real-time maritime movement data with an agent-based global supply chain model, using the 2021 Los Angeles–Long Beach (LALB) port congestion as a representative case. The results indicate that the congestion event contributed to an increase of 0.36 million tons of CO2-equivalent greenhouse gas (GHG) emissions. The total estimated supply chain loss was $121.7 (115.5-137.0) billion, with passive GHG emissions reductions due to decreased production amounting to 78.8 million tons. Furthermore, the loss incurred for a one-day delay of a $1 USD cargo was calculated at $0.04 (or a 4% ad valorem tariff). Among the total losses, 14% occurred in regions outside the United States, notably affecting the rest of the Americas, the Middle East, and China due to reduced demand in the United States. Our findings suggest that the losses do not persist indefinitely with congestion, with losses only surging when congestion intensifies. Furthermore, we assessed the environmental and supply chain-wide benefits of five resilience measures Corresponding measures should be implemented at different stages of congestion events. This approach can be extended to evaluate the environmental and supply-chain impacts of congestion and disruptions at other ports or canals worldwide. Our results offer vital insights for policymakers and port authorities seeking to bolster resilience and preparedness, alleviating the global cascading impacts of port congestion.

Paper ID: 154

Waste separation systems in Central Tokyo: Evaluating linguistic and structural barriers faced by foreign residents

Farai Maringa, Ori Akemi, Nkweauseh Longfor
Sophia University, Japan;
Email: fmaringa95@gmail.com

Abstract:

This study evaluates the linguistic and structural barriers affecting waste separation compliance and understanding among foreign residents in Central Tokyo, also known as the special 23 wards. As Japan's number of foreign residents grows, municipalities face pressure to ensure inclusive governance for all essential services, including waste separation systems. Despite Japan's globally recognised waste separation systems, ward-level rule variations create significant adaptation challenges for foreign and domestic migrants alike. Employing a mixed-methods approach framed by the Cultural Theory of Risk, this research combines quantitative surveys of foreign residents with a comparative sample of Japanese residents, alongside qualitative interviews with ward officials from three high-density wards: Shinjuku, Taito, and Minato. Findings reveal that non-compliance extends beyond language limitations to fundamental structural flaws. Key barriers include: (1) non-standardized rules across wards, cited by officials as a primary compliance hurdle; (2) a broken information chain where over 50% of foreign respondents reported never receiving formal waste separation orientation and some not receiving waste separation guidelines due to poor communication from building managers; and (3) specific category confusion, particularly for oversized garbage requiring Japanese phone booking and separating recyclables from combustible waste. The Cultural Theory of Risk illuminates how compliance and understanding patterns align with four cultural worldviews: Hierarchist (compliant), Egalitarian (community-adapters), Individualist (independent), and Fatalist (overwhelmed). The study concludes that improving compliance requires a structural redesign of information and governance systems, moving beyond blaming residents or enforcing behavioural change. Recommendations include promoting inter-ward coordination, establishing direct municipal-to-resident communication channels to bypass unreliable building managers, and developing targeted and intricate visual tools for difficult waste categories. These insights contribute to sustainable urban governance literature and offer a transferable framework for global cities managing diverse populations while achieving environmental benefits such as increased recycling rates and reduced landfill use.

Paper ID: 155

Synergistic effects of cap-and-trade and voluntary emission reduction offset mechanisms: Evidence from China's coal-fired power sector

Rui-ze Qin[1,2,3,4,5], Yi-Ming Wei[1,2,3,4,5]

[1]Center for Energy and Environment Policy Research; [2]School of Management, Beijing Institute of Technology; [3]Basic Science Center for Energy and Climate Change; [4]Beijing Key Lab of Energy Economics and Environmental Management; [5]Beijing Laboratory for System Engineering of Carbon Neutrality;
Email: qinruize0721@163.com

Abstract:

Since the reactivation of China's Certified Emission Reduction (CCER) mechanism, whether offsets can achieve synergy with the cap-and-trade system remains contested. Existing studies focus on institutional design and macroeconomic assessment, leaving the micro-level pathways through which offsets shape regulated firms' abatement and technology investment decisions insufficiently explored. Computable general equilibrium models struggle to capture path dependence, empirical approaches cannot evaluate new policies ex ante, and game-theoretic models adopt strategy spaces too simplified to represent continuous investment adjustments. This study develops an agent-based model of 2,604 coal-fired generating units across 937 enterprises, capturing heterogeneity in risk attitudes, technology awareness, and carbon price expectations, and simulates 14 core scenarios combining two carbon price trajectories with three offset limits and two CCER-to-allowance price ratios. Four findings emerge. First, CCER exerts opposing effects on technology investment: when priced close to allowances, it produces a crowding-in effect that steers portfolios toward higher-abatement technologies; when priced substantially below allowances, it crowds out investment as firms substitute offset purchases. Second, the interaction between CCER and the carbon market is conditional—under conservative pricing, CCER counteracts abatement, while under aggressive pricing the two mechanisms are synergistic. Third, policy effectiveness varies temporally: scenarios with CCER priced near allowances take effect earlier, delivering cumulative reductions exceeding 1.2% by 2030, whereas lower-priced CCER scenarios are substantially delayed or ineffective. A parametric scan of 56 combinations with multi-criteria decision analysis robustly identifies an offset limit of 7–10%, a CCER-to-allowance price ratio near 90%, and an aggressive carbon price trajectory as the policy optimum across four weighting schemes. The study provides micro- and macro-level evidence on ETS–CCER coordination and empirical reference points for calibrating carbon price trajectories, offset limits, and CCER price ranges.

Paper ID: 157

Environmental and urban developmental impacts of building material stocks in central business districts of Metro Manila, Philippines

Francis Urmenita[1,2], Marianne Faith Martinico-Perez[1], Masatoshi Hasegawa[1], Hiroaki Shirakawa[1], Kenneth Jae Elevado[1,3], Hiroki Tanikawa[1]

[1]Nagoya University, Japan; [2]Department of Economy, Planning, and Development (Philippines); [3]De La Salle University;

Email: martinico-perez.marianne.faith.gauran.y5@f.mail.nagoya-u.ac.jp

Abstract:

The ongoing urbanization is expected to drive a surge in new building developments in the Philippines. Analyzing the consumption and accumulation of primary construction materials is crucial for anticipating environmental impacts and waste potential and guiding low-carbon urban planning. This study aims to quantify the material stocks (MS) of primary building construction and estimate the embodied carbon of material stocks in central business districts (CBDs) in Metro Manila, Philippines. Using the bottom-up method of estimating material stocks, the building footprint data were taken from OSM Buildings (2025) and Google's Open Buildings 2.5D Temporal Dataset. The material intensity coefficients and embodied carbon factors were based from the local and regional estimations in the Philippines. The combined results from the three CBD showed an accumulation of 49.46 Million tons (Mt) of concrete and steel reinforcements in 2023, an increase by 11.75% since 2016. In 2023, Makati CBD had the highest cumulative MS at 20.10 Mt, followed by BGC (17.78 Mt), and Ortigas (11.58 Mt). The spatial analysis revealed the distribution of low-rise residential areas in Ortigas and Makati, while BGC exhibited a more uniform distribution. The Ortigas recorded the highest MS density at 8.58 Mt/km2 (1,098.77 t/cap) as a result of its compact land area while Makati had the lowest MS density of 6.57 Mt/km2 (559.91 t/cap). The cradle-to-gate Life Cycle Assessment of the embodied carbon showed that Makati had the highest total embodied emissions at 6.26 MtCO2e, followed by BGC at 5.71 MtCO2e and Ortigas at 3.69 MtCO2e in 2023. It also reflects that BGC had the highest emissions per height classification, likely due to the modern design standards and broader urban development patterns. This study emphasizes that incorporating MS and life cycle assessment data into local and regional planning is critical for supporting the Philippines' broader sustainability goals as a developing country.

Paper ID: 160

Who should be responsible for e-waste management? A qualitative study of the perceptions of Indian consumers

Rama Mohana Turaga[1], Sumitra Nair[2]
[1]Indian Institute of Management Ahmedabad, India; [2]Ashoka University, India;
Email: mohant@iima.ac.in

Abstract:

Extended producer responsibility (EPR) has been a dominant policy approach to address the problem of electronic waste (e-waste). Although EPR places primary responsibility on producers of electronic goods, consumers must play an important role in effective implementation by, for example, willing to return the products after their useful life. Existing literature on consumer perceptions of e-waste management is dominated by quantitative studies that draw on existing behavioural theories. This studyadopts a qualitative approach to assess consumer perceptions related to e-waste management in India. We conducted semi-structured interviews of 30 consumers representing different kinds of users - students, working professionals, homemakers, and retirees - focussing on their perceptions on the responsibility of various actors in the e-waste management ecosystem. Our findings indicate that Indian consumers trust the government to build the regulatory framework, but not to handle the waste. While they endorse the EPR approach of making manufacturers responsible for e-waste, rather than the conventional policy rationale for this instrument, which primarily focuses on incentivising more environmentally-responsible product design, the consumers in our study identify “expertise” of the manufacturers as the primary rationale for making producers responsible. While they frame their own sense of responsibility in terms of broad phrases like “maximum use,” and “responsible consumption,” and even foresee product prices rising marginally to pay for any additional costs that manufacturers may levy for recycling, there is very limited imagination of a circular economy or afterlife of these products. According to the consumers, the toxicity of materials used in electronic products and the increasing complexity of product design makes their safe dismantling, segregation, and recycling extremely complex, which appears far above the technical or financial capacity of the other actors, including the government. Based on these findings, we discuss the implications for the design and implementation of EPR regulations in India and beyond.

Paper ID: 162

Life cycle assessment of scalable R2R-manufactured flexible perovskite solar cells

Mae Xerzel Ouano[1], Erica Magliano[2], Ilker Dogan[3], Sebastien Lizin[1]

[1]Centre for Environmental Services, Hasselt University, Diepenbeek 3590, Belgium; [2]Istituto di Struttura della Materia National Research Council (CNR-ISM), Rome 00133, Italy; [3]TNO, High Tech Campus 21, Eindhoven 5656 AE, The Netherlands;

Email: maexerzel.ouano@uhasselt.be

Abstract:

Perovskite-based photovoltaics are emerging as low-carbon alternatives to conventional solar technologies, with flexible perovskite solar cells (f-PSCs) offering additional advantages due to their lightweight design and mechanical flexibility. These properties enable integration into vehicles, buildings, and portable systems, yet the environmental implications of f-PSCs remain insufficiently assessed. Existing life cycle assessment (LCA) studies focus primarily on rigid perovskite modules, leaving a critical gap in understanding the resource and energy demands of scalable flexible designs, especially using roll-to-roll (R2R) manufacturing processes. This study addresses this gap by assessing the environmental impacts of five flexible perovskite cell architectures, considering only scalable, R2R-compatible manufacturing processes. The LCA follows a cradle-to-gate system boundary, from raw material extraction to module manufacturing, and a functional unit of 1 m² of flexible perovskite module. Input data was derived from pilot-scale information from manufacturers and supplemented with literature data. Based on the results, the global warming potential (GWP) of all five scenarios is approximately 29 kg CO_2 eq./m², comparable to that of rigid perovskite modules and 80% lower than that of c-Si modules. The most environmentally impactful processing step is buffer layer deposition because of the high nitrogen consumption in spatial atomic layer deposition (sALD), a promising deposition technique for thin, flexible films due to its fast deposition speed and scalability. Processes using sputtering are also environmental hotspots due to their high energy requirements. By focusing on R2R-compatible processes and evaluating previously unassessed deposition techniques, this study better approximates the environmental impacts of a future commercial production line for f-PSCs. From these results, more relevant guidance can be provided for integrating ecodesign and resource-efficiency principles into the early development of f-PSC technologies. Future work will forecast environmental performance under industrial-scale production to identify pathways toward more sustainable photovoltaic manufacturing.

Paper ID: 163

Streamlining criticality assessment: introducing QuintESSENZ for product-level evaluation

Nikolai Darius Richter, Vanessa Bach, Kim Maya Yavor, Sylvia Marinova, Matthias Finkbeiner
Technical University Berlin, Germany;
Email: nikolai.darius.richter@tu-berlin.de

Abstract:

Resource criticality is a multifaceted concept captured by assessment methods that employ a wide range of indicators. One of these methods is the Integrated Method to Assess Resource Efficiency (ESSENZ), which applies 18 categories to assess criticality on product level. While this diversity of indicators allows for a comprehensive assessment, it can make application and interpretation challenging. To support a more practical implementation while maintaining comparable outcomes, QuintESSENZ is introduced as a streamlined version of ESSENZ considering six categories.

The development of QuintESSENZ followed a five-step approach, in which existing ESSENZ categories were evaluated based on statistical correlation, background data quality, discriminatory power, relevance in established case studies, and a decision hierarchy assessment.

From the ten categories in socio-economic availability, this procedure identified a core set of two categories: political instability and concentration of reserves. For physical availability and societal acceptance, the original three categories are applied. Environmental impacts are represented by the lead indicator carbon footprint.

A comparison of ESSENZ and QuintESSENZ indicator results for all 48 materials revealed a high level of consistency between the two methods. Both identified the same materials as critical (e.g., palladium, platinum, and rhenium). Differences in relative ordering were minor overall and less pronounced among materials of higher criticality. Several sensitivity analyses confirmed the robustness of the category selection approach across different weighting schemes and data updates.

QuintESSENZ and ESSENZ have been applied to the same case studies (e.g., smartphone, and aircraft) to demonstrate and discuss the applicability as well as potential limitations.

While ESSENZ remains the recommended approach for a comprehensive resource efficiency assessment supporting strategic material selection and supply decisions, QuintESSENZ can be applied as a first step to identify potential hotspots to focus on in further analysis.

Paper ID: 164

Closing the data gap: Enhancing Life Cycle Assessments for packaging

Jennifer Zhang[1], Experience Nduagu[1], Kirti Richa[1], Elizabeth Avery[2], Rafael Auras[3], Timothee Roux[4], Nathália Antoniazzi[5], Tasja Hafner-Kuhn[5], Katja Wack[5], Andrin Gstöhl[5], Manfred Tacker[5]

[1]ExxonMobil Technology and Engineering Company, United States of America; [2]Trayak Inc, United States of America; [3]Michigan State University, School of Packaging, United States of America; [4]Exxon Mobil Corporation, United States of America; [5]Circular Analytics TK GmbH, Austria;
Email: experience.i.nduagu@exxonmobil.com

Abstract:

Several Life Cycle Assessments (LCAs) have been conducted to assess the potential environmental impacts of packaging materials, with notable improvements in data quality over the years through regular updates and development. However, several data gaps remain unaddressed for packaging LCAs, particularly around the availability and quality of inventory data. This study explores data gaps in packaging LCAs, focusing on packaging-related product losses and application-specific end-of-life (EoL) rates.

Although packaging cannot be considered independently from the products it contains, LCA studies have primarily focused on packaging materials, often neglecting the potential impacts of the packaged products. Packaging failures and breakage during manufacturing, transportation, and distribution—and the resulting product losses—are frequently overlooked or omitted. This oversight represents a key gap because the environmental impacts of product losses can greatly exceed those of packaging. Data and methods from recent research addressing these gaps will be showcased.

EoL stage modeling is another area impacted by data gaps. Packaging LCAs sometimes rely on outdated estimates and generalized material-specific EoL disposition rates (e.g., landfill, recycling, incineration), typically sourced from country-level datasets (e.g., the US EPA and Eurostat) for different materials. With increasing investments towards addressing EoL challenges and improving recycling rates, developing more representative and robust LCAs will necessitate high-resolution, frequently updated data on EoL disposition rates. Research methods and insights from our work on this topic will be discussed.

Multi-stakeholder collaboration and participation throughout the product supply chain, along with engagement by LCA practitioners, can help bridge these data gaps by developing high-quality, reliable, and transparent life-cycle inventory datasets for packaging systems. The datasets developed can be integrated into LCA databases to support more comprehensive life-cycle inventories, serving as a resource for LCA practitioners to conduct robust LCAs and to inform business and policy decisions on packaging.

Paper ID: 166

Optimization of carbon reduction & pollution control in the urban-industrial systems

Lu Sun[1], Chenyang Wang[1], Chunlei Du[1], Zhaoling Li[2]
[1]Xi'an Jiaotong University, People's Republic of China; [2]Shanghai University, People's Republic of China;
Email: sunlu2021@126.com

Abstract:

Climate change mitigation and adaptation are hot issues in recent years. With the advancement of industrialization and urbanization, China is facing severe challenges and pressures in energy conservation, emission reduction, and environmental pollution prevention and control. As the key platform of human activities, urban metabolism optimization plays a key role in industrial green and low-carbon development and resource recycling, it's an effective way to promote energy conservation, emission reduction, and sustainable development in the urban complex systems. This study analyzes the direct benefits of resource and energy conservation in the symbiosis of eco-industrial parks and industries, and further reveals the benefits of pollution reduction and carbon reduction brought by regional energy systems from the perspective of urban complex ecosystems, considering the future trends of technological development and regional circular economy goals. Finally, an optimized path for industrial low-carbon development and material/energy flows at the urban scale was proposed to promote the achievement of the carbon peak target and sustainable development goals for the cities.

Paper ID: 167

Assessing ev lithium-ion battery recycling performance, eu battery recycling targets, and profitability under uncertainty: a system dynamics and monte carlo simulation framework

Yuqiong Zhang, Yang Cheng
Aalborg University, Denmark;
Email: yuqzha@mp.aau.dk

Abstract:

This study develops a quantitative evaluation framework based on system dynamics modeling combined with Monte Carlo simulation to assess EV lithium-ion battery recycling performance, EU regulatory targets, and profitability under uncertainties in EV sales, battery lifetime, and recycling efficiency. Using estimates of EV sales in EU-27 and first- and second-EoL battery volumes under dynamic lifetime assumptions, material flows across recycling stages are simulated over 2015–2040. Results show that EU recycled content targets are not fully met, with lithium and cobalt exhibiting the highest risk of non-compliance. Required recycling capacity increases significantly, reaching 22–34 GWh in 2030 and 207–431 GWh by 2040 under two lifetime scenarios. Scenario analysis identifies two practical improvement strategies that balance recycled content and profitability. First, the implementation of the Digital Battery Passport enhances collection and pre-treatment efficiency, increasing recycled content (Li, Ni, Co) by up to 39.5%. Second, increasing second-life utilization in the short term and reducing it in the long term improves profitability as economic conditions shift toward higher metal recovery. Overall, the study shows that achieving EU recycling targets, strengthening secondary material supply, and ensuring cost-efficient recycling systems require expanded recycling capacity, optimized collection and pretreatment, dynamic second-life utilization, scaled transportation systems, and continuous evaluation under uncertainty.

Paper ID: 168

Differential population and land-use dynamics across flood frequency zones in Lao PDR

Khamphone Soulivong[1], Hiroaki Shirakawa[2], Marianne faith Martinico-Perez[3], Mastoshi Hasegawa[4], Hiroki Tanikawa[5]

[1]Nagoya University, Japan; [2]Nagoya University, Japan; [3]Nagoya University, Japan; [4]Nagoya University, Japan; [5]Nagoya University, Japan;

Email: soulivongkhamphone@gmail.com

Abstract:

Flood-prone areas are often characterized by rapid population growth and land-use transformation, yet empirical evidence from least-developed countries remains scarce. This study examines long-term changes in population distribution and land cover/land use within flood inundation hazard areas across Laos, with explicit attention to flood frequency classes. This study presents a novel nationwide assessment integrating population dynamics and land-use change within flood hazard zones.

We delineated flood inundation hazard areas using the Global Flood Database v1 (2000–2018), classifying them into three frequency categories based on flood occurrence: low (1–3 years), medium (4–9 years), and high (≥10 years). Population changes between 2000 and 2020 were analyzed using WorldPop gridded data. Additionally, we assessed land cover and land-use changes from 2016 to 2024 using Dynamic World V1, focusing on transitions among agriculture, forest, urban, water, and other classes.

Our analysis reveals that population growth within flood-prone areas is concentrated primarily in low- and medium-frequency flood zones, while high-frequency zones remain sparsely populated with stagnant demographic change. Several provinces, including Savannakhet, Bolikhamxai, and Champasak, experienced substantial population increases in low-frequency flood areas between 2000 and 2020. Land-use analysis indicates a marked expansion of agricultural and urban areas in these low-frequency zones, accompanied by a notable decline in forest cover. In contrast, land-use changes in high-frequency zones are comparatively limited, though increases in forest and water areas suggest ongoing natural or managed hydrological processes.

These findings indicate that flood frequency plays a critical role in shaping population settlement patterns and land-use dynamics in Laos. The results highlight the necessity of distinguishing flood hazard zones by recurrence intervals when evaluating exposure, vulnerability, and long-term development trajectories. This study provides critical baseline empirical evidence to support flood risk management and land-use planning in data-scarce contexts.

Paper ID: 169

Life Cycle mechanistic perspectives on carbon mitigation in low-carbon agriculture

Solhee Kim[1], Jeongbae Jeon[2], Taegon Kim[1]
[1]Jeonbuk National University, Korea, Republic of (South Korea); [2]Spatial Information Research Institute, Korea, Republic of (South Korea);
Email: solhee1101@jbnu.ac.kr

Abstract:

Low-carbon agricultural technologies (LCATs) are central to climate mitigation strategies in the agri-food sector. While life cycle assessment (LCA) is widely used to quantify their potential greenhouse gas (GHG) savings, actual emission reductions at the system level often diverge from LCA-based estimates. This gap stems from dynamic economic and behavioral mechanisms that mediate how technologies are implemented and scaled. To address this issue, we propose a conceptual and empirical synthesis of four key mechanisms influencing carbon outcomes of LCATs: complementary effect, substitution effect, technology spillover effect, and energy rebound effect.

The complementary effect amplifies GHG reductions when technologies are adopted synergistically (e.g., combining conservation tillage with nutrient management). The substitution effect captures carbon savings from replacing high-emission inputs (e.g., fossil fuel, synthetic fertilizer) with low-carbon alternatives. Technology spillovers extend carbon benefits spatially or socially beyond the point of initial adoption, while the rebound effect offsets expected reductions when efficiency gains lead to increased production intensity.

Our findings underscore the need to integrate mechanism-aware modeling with conventional LCA to better reflect real-world carbon dynamics in agriculture. A combined framework will allow for more accurate prioritization of mitigation options, highlighting the importance of context-specific implementation strategies that maximize synergies and limit rebounds.

Paper ID: 182

Hydrogen energy transitions and critical mineral supply chains in the Indo-Pacific

Benjamin McLellan
Kyoto University, Japan;
Email: b-mclellan@energy.kyoto-u.ac.jp

Abstract:

Many countries in the Indo-Pacific region have plans for hydrogen within their sustainable energy transition plans. While not the most signicant challenge facing a hydrogen transition, the critical mineral requirements underlying these plans do pose a potential risk to their acheivement. This study identifies the key critical minerals for hydrogen technologies, and their existing industrial ecosystem in the Indo-Pacific. At the same time, it considers the social and environmental impacts of such transitions, with a focus on the distributional justice implications at a local level. The results will identify technical, social and environmental barriers, and enabling policies on a regional, national and sub-national level.

Paper ID: 183

Material Stock Estimation of Single Residential Buildings in the Philippines from 2008 to 2023

Kenneth Jae Elevado[1,2], Marianne Faith Martinico-Perez[1], Masatoshi Hasegawa[1], Hiroaki Shirakawa[1], Anthony Shun Fung Chiu[2], Hiroki Tanikawa[1]

[1]Graduate School of Environmental Studies, Nagoya University, Nagoya, Japan; [2]Gokongwei College of Engineering, De La Salle University, Manila, Philippines;
Email: kenneth.elevado@dlsu.edu.ph

Abstract:

In 2020, records show that the number of single residential buildings (SRBs) in the Philippines was more than 22 million, accounting for approximately 88% of the total occupied housing units in the country. This was significantly higher than the global estimates in the same year, which was around 47%. The expansion of SRB constitutes an increased demand of construction materials. However, the embedded material stocks (MS) in the built environment, including the implications of their end-of-life outflows, remain insufficiently quantified. This study estimates the MS of SRBs in the Philippines from 2008 to 2023 using bottom-up approach based on statistical data, and established material intensities in the country. The materials considered in the estimates were concrete, granular fill, steel, and other building construction materials, namely: aluminum, cement board, lumber, glass, gypsum board, iron, plaster, plywood, poly vinyl chloride, polyethylene and stone. Results show that the SRB MS grew from 4.04 billion metric tons (Bt) to 4.29 Bt in 2008 and 2023, respectively, with an annual increase from new construction amounting to 12 million metric tons (Mt) in 2009 and 22 Mt in 2023. These are equivalent to 43.6 metric tons per capital (mt/cap) of SRB MS in 2009 and 37.3 mt/cap in 2023, indicating possible housing shift to non-SRBs over the years. Among the materials included in the latest estimates, concrete had the highest share of 73%, followed by granular fill with 10% of the total SRB MS. The share of steel was 4%, while the other materials considered were about 13%. The results of the study provide a baseline for SRB MS in the Philippines, aimed to support managing construction materials demand, planning for viable construction and demolition waste management systems, and developing circular economy strategies in the Philippine infrastructure.

Paper ID: 186

Ecosystem service demand relationship and trade-off patterns in urban parks across China

Shuyao Wu[1], Delong Li[2], Kai-di Liu[3], Wentao Zhang[3], Binbin V. Li[4], Shuangcheng Li[5], Lumeng Liu[1], Ximan Sun[1], Weili Duan[6], Zhonghao Zhang[1]

[1]Hohai University, China; [2]Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Science, China; [3]Shandong University, China; [4]Duke University, USA; [5]Peking University, China; [6]Xinjiang Institute of Ecology and Geography, Chinese Academy of Science, China;
Email: wushuyao@hhu.edu.cn

Abstract:

Urban parks play a vital role in delivering various essential ecosystem services that significantly contribute to the well-being of urban populations. However, there is quite a limited understanding of how people value these ecosystem services differently. Here, we investigated the relationships among nine ecosystem service demands in urban parks across China using a large-scale survey with 20,075 responses and a point-allotment experiment. We found particularly high preferences for air purification and recreation services at the expense of other services among urban residents in China. These preferences were further reflected in three distinct demand bundles: air purification-dominated, recreation-dominated, and balanced demands. Each bundle delineated a typical group of people with different representative characteristics. Socio-economic and environmental factors, such as environmental interest and vegetation coverage, were found to significantly influence the trade-off intensity among service demands. These results underscore the necessity for tailored urban park designs that address diverse service demands with the aim of enhancing the quality of urban life in China and beyond sustainably.

Paper ID: 187

Flowing revenue: The role of water resource taxation in China's water stewardship

Yu Zheng
Shantou University, China;
Email: yuzheng@stu.edu.cn

Abstract:

Does pricing water lead to an increase in water resources? This article provides quasi-experimental estimates of the impact of taxing water on water resources by leveraging a unique natural experiment: the staggered introduction of water resource tax across China. In a difference-in-differences (DiD) paradigm, I find that the rollout of water resource taxation in China had a positive impact on water conservation, with a pronounced increase in surface water of at least 14.45%. However, there was no significant decrease in over-quota water and ground water within over-extracted aquifer area. Interestingly, the moderating effect of tax intensity yielded seemingly divergent effects on surface and ground water, which may somehow account for the policy's less discernible influence on the latter. This study sheds fresh light on the optimization of water resource taxation and the promotion of sustainable water stewardship.

Paper ID: 198

An optimization model of an integrated electric bus fleet

Matthew Keh, Charlle Sy
De La Salle University, Philippines;
Email: charlle.sy@dlsu.edu.ph

Abstract:

As electric vehicles become more common in public transportation, agencies need integrated, operations-focused tools that jointly manage timetables, vehicle and crew assignment, and charging to maintain reliable and cost-effective service. This paper presents an integrated optimization model for daily operations of a single-depot mixed fleet consisting of battery electric buses (BEBs) and internal combustion engine buses (ICEBs). The model formulates timetabling, vehicle assignment, charging decisions, and crew scheduling within one mixed-integer linear program.

Profit is maximized by linking fare revenue to realized boardings, which depend on stop-level arrivals, vehicle capacity, and passenger balking. Flexible headways allow schedules to adapt to time-varying demand while preserving operational feasibility. Energy decisions incorporate state-of-charge tracking, charger capacity limits, and partial or interruptible charging, with the ability to represent time-of-use electricity prices and multiple charging power levels. Interlining across routes is allowed with buffer times to limit delay propagation, and crew legality is enforced through driving-time limits, break requirements, and relief constraints. Because each decision area interacts strongly with the others, the model optimizes them jointly rather than sequentially.

Scenario analyses evaluate fixed versus flexible headways, interlining on and off, different BEB-to-ICEB fleet ratios, and variations in charger quantity and power. Results show that demand-responsive timetables and integrated assignments increase boardings and resource utilization, while pre-assigning trips before charging introduces depot congestion and reduces feasibility. Interlining decreases idle time and can reduce fleet needs when buffers are sufficient. Higher BEB shares increase charging load and may reduce profitability without adequate charger capacity or pricing strategies. Integrating crew rules with vehicle and charging decisions reduces overtime and avoids violations.

Paper ID: 203

A bi-objective decision model for WEEE circular plant operation: a disassembly bill of materials approach

Zhiqin NI
Xi'an Jiaotong-Liverpool University, China, People's Republic of;
Email: zhiqin.ni@xjtlu.edu.cn

Abstract:

Establishing circular plants to recover waste of electrical and electronic equipment (WEEE) has become a worldwide practice for manufacturers. Circular plants support a closed-loop production and consumption system by reusing products or basic materials from the recovery operation. Prior research focuses on optimizing selective disassembly planning to determine the best disassembly routes and sequences for extracting high-value components and achieving economic objectives. However, it often pays less attention to selective disassembly residues—typically low-value components that are often reclaimed as waste if not further disassembled and recycled. This paper constructs a bi-objective integer linear programming model to maximize the WEEE recovery rate and minimize recovery costs, guiding disassembly planning for circular plants using a disassembly bill-of-materials approach that recovers the entire product, including both high-value and low-value items. The optimal solutions provide optimal recovery or disposal options for each item across all product hierarchies—products, sub-assemblies, and components comprehensively. A sum utility function is proposed to convert the bi-objective problem into a single-objective problem, which is then solved. A real-life case study of disassembly planning for multi-functional copiers is presented, validating the effectiveness of a bi-objective hierarchical decision model. The results show that reuse is the economic and environmental anchor of the circular economy for WEEE recovery. Circular plant operators can navigate trade-offs of the two conflicting objectives under different regulatory regimes. In Europe, the optimal recovery and disposal decision may yield an 86.2% recovery rate at a cost of 1.81 million. This study enriches the literature on WEEE disassembly planning by offering a holistic decision-making model for the entire product, based on a disassembly bill of materials, that guides circular plant operations in navigating the two conflicting objectives: recovery rate and recovery costs.

Paper ID: 205

Scalable validation of intelligent decision-making systems for energy transition minerals supply chains

Mansur Arief
King Fahd University of Petroleum and Minerals, Saudi Arabia;
Email: mansur.arief@kfupm.edu.sa

Abstract:

The accelerating global demand for critical minerals driven by the energy transition to renewable technologies and electric vehicles has spurred the adoption of AI-based decision-making systems to manage complex supply chains under deep uncertainty. These systems increasingly guide strategic decisions on resource extraction, supplier diversification, and supply chain planning. However, deploying AI in such high-stakes domains without rigorous validation risks catastrophic cascading failures across interconnected supply networks. Traditional validation approaches, such as naive Monte Carlo testing, are fundamentally inadequate for these systems because critical failures are rare events embedded in high-dimensional uncertainty spaces spanning geological, geopolitical, and market dimensions. This paper presents a scalable verification and validation (V&V) framework for AI-driven decision-making in critical minerals supply chains. We extend scalable rare-event simulation methods originally developed for safety-critical cyber-physical systems to the energy transition minerals supply chain domain. Specifically, we adapt a deep importance sampling framework to handle dynamic policies to identify failure modes in AI supply chain policies, such as scenarios where geopolitical uncertainty, demand shocks, or logistic disruptions cause the policy to recommend actions leading to severe supply shortfalls. We integrate this V&V framework with a Partially Observable Markov Decision Process (POMDP) formulation for critical mineral sourcing under geological uncertainty, enabling validation of policies before real-world deployment. Through a case study, we demonstrate that our framework can identify critical failure scenarios orders of magnitude faster than conventional testing while providing statistical guarantees on failure rate bounds under certain mild uncertainty bound assumptions. The results offer policymakers and supply chain managers a principled methodology for highlighting the failure modes of AI decision policies, thereby building trust in AI-assisted mineral resource decisions and balancing the urgency of energy transition with the need for robust, validated decision support systems for sustainable resource development and resilient energy systems.

Paper ID: 206

Prospective evaluation of polyolefin-derived pyrolysis wax as a phase change material: thermophysical characterization and LCA

Amir Shefy[1], Sabrina Spatari[1,2]
[1]Grand Technion Energy Program, Technion, Israel; [2]Faculty of Civil and Environmental Engineering, Technion, Israel;
Email: Amir.Shefy@campus.technion.ac.il

Abstract:

Rising global temperatures are increasing the demand for heating and cooling in buildings, contributing significantly to global greenhouse gas emissions. Phase change materials (PCMs) offer an effective strategy to improve building energy efficiency by storing and releasing thermal energy within the human comfort temperature range. However, conventional PCM feedstocks are often derived from fossil or resource-intensive processes, limiting their overall sustainability. This study investigates the potential of polyolefin waste, such as polypropylene (PP), high-density polyethylene (HDPE), and low-density polyethylene (LDPE), as a feedstock for PCM production via pyrolysis. Waxes obtained from the pyrolysis of each waste stream were first evaluated using differential scanning calorimetry to assess their thermophysical suitability for thermal energy storage applications. Among the tested materials, HDPE-derived wax exhibited the most favorable thermal behavior and was subsequently post-treated to further enhance its performance. This treatment increased the peak melting temperature to 38.8 °C and the latent heat of fusion to 172.43 kJ/kg, nearly doubling the thermal storage capacity and achieving performance comparable to commercial paraffin-based PCMs. Based on evaluated thermophysical properties, a cradle-to-gate life cycle assessment (LCA) was conducted for the HDPE-derived wax using a functional unit of 100 MJ/m^3 of latent thermal storage. The environmental performance was compared against conventional PCMs, including paraffin, polyethylene glycol, capric acid, and sodium sulfate decahydrate. The LCA results indicate that using plastic waste, specifically HDPE waste, as PCM feedstock can reduce global warming impact, human toxicity, and land use by over 90% compared with conventional organic PCMs. These findings highlight the opportunity to valorize plastic waste into functional thermal energy storage materials, supporting circular-economy strategies while reducing environmental impacts in the built environment.

Paper ID: 208

Repurpose or recycle? a blockchain architecture for trustworthy artificial intelligence-enabled battery end-of-life routing in sustainable supply chain

Xinlai Liu[1], Charlle Sy[1], Size Liu[1], Sanjanapatel Hanumanthareddy[2], H. Oliver Gao[1,3]

[1]Systems Engineering Program, Cornell University, Ithaca, NY; [2]Cornell Ann S. Bowers College of Computing and Information Science, Cornell University, Ithaca, NY; [3]School of Civil and Environmental Engineering, Cornell University, Ithaca, NY;
Email: charlle.sy@dlsu.edu.ph

Abstract:

Millions of electric vehicle (EV) batteries will soon reach end-of-life, creating an urgent need for trustworthy routing decisions: repurposing for second-life usage or recycling for material recovery. In current practice, recyclers often tend to adopt conservative recycling strategies due to the lack of battery lifecycle history and uncertain liability for second-life failures, resulting in increased loss of reusable batteries and reduced profits for battery owners. This paper presents blockchain architecture for Trustworthy Artificial Intelligence (AI) to facilitate repurpose-or-recycle decision-making in battery end-of-life supply chain. Following the unified blockchain architecture, we develop a Trustworthy AI-enabled workflow for battery end-of-life routing that integrates intake screening, triage evaluation, deep diagnosis, and final routing decisions, while preserving data confidentiality through off-chain storage. To validate the approach, we conducted a demonstrative case using collaborating company data to present the blockchain-based services, formalize battery routing rules with engineering-ready thresholds and economic feasibility constraints, and conduct performance evaluation under three realistic inputs: human operators, AI agents, and IoT devices. Results show that the blockchain can provide a cross-stakeholder battery lifecycle information-sharing, thereby providing a practical foundation for deploying Trustworthy AI models for battery end-of-life routing in supply chain.

Paper ID: 213

Artificial Intelligence based solid waste management solutions for enhanced resource recovery

Yu Won Tan, Ali Zoungrana, Oscar Amponsah, Qiuyan Yuan
University of Manitoba, Canada;
Email: qiuyan.yuan@umanitoba.ca

Abstract:

Growing concern of waste generation and resource depletion has necessitated efficient and sustainable solid waste management (SWM) systems to enhance resource recovery (ERR). While resource recovery has recently gained significant attention, traditional SWM systems have many limitations. The emergence of Artificial Intelligence (AI) technology introduces an exciting opportunity to optimize resource recovery by implementing smart automation and other emerging intelligent technologies into waste collection, sorting, treatment, and disposal processes. Studies into the most used Machine Learning (ML) and Deep Learning algorithms which are employed to analyze resource recovery approaches can accelerate functional solutions to optimize these processes. Algorithms, such as Artificial Neural Networks (ANNs), Support Vector Machines (SVMs) and Convolutional Neural Networks (CNNs) have been established in performing tasks in municipal solid waste processes such as prediction, detection, and monitoring. This review critically examines the application of these algorithms across various stages of MSW management chain. Through extensive analysis of available literature, the study identifies the roles these algorithms play in prediction, classification, detection, and monitoring tasks that ensure circularity and enhance efficiency in MSW operations. The findings highlight how AI and ML is gradually transforming conventional MSW management practices into data-driven, adaptive, circular and resource efficient economy. Various challenges associated with data scarcity, model standardization, and real-world scalability are discussed, suggesting innovative future perspectives to address these gaps.

Paper ID: 215

Electricity-Carbon-Hydrogen Coupling Mechanism and Offset Ratio Optimization under the Inclusion of CCER Green Hydrogen

Mingyue Hu, Tiantian Feng
China University of Geosciences, Beijing;
Email: 17662886858@163.com

Abstract:

Although the restart of the China Certified Emission Reduction (CCER) mechanism has provided a channel for green hydrogen to obtain an environmental premium, systematic quantitative evidence is still lacking on whether the current 5% offset ratio is suitable for multi-market coupling development and the cross-market dynamic transmission effect of "carbon price-electricity price-hydrogen cost" triggered by green hydrogen's inclusion in CCER. To address this, this paper constructs a system dynamics simulation system for the electricity-carbon-hydrogen market coupling, embeds the Levelized Cost of Hydrogen (LCOH) calculation model, and introduces the electrolyzer learning curve. Through joint regulation of key parameters such as offset ratio and equipment utilization hours, 22 policy and technology scenarios are set to simulate the system's dynamic evolution from 2024 to 2034. The research results show that: ①There is a significant mutual transmission and feedback mechanism among carbon price, electricity price, and hydrogen cost. The expansion of CCER supply will suppress its own price and divert quota demand, thereby affecting the carbon cost transmission path, highlighting the necessity of coordinated regulation of multiple markets; ②The current 5% offset ratio may not be suitable for changes in market structure. It is recommended to implement a dynamic offset management mechanism to balance the effectiveness of the carbon market and the incentives for emission reduction projects; ③If the equipment utilization rate is simply increased without adequate renewable energy support and excessive reliance on purchased green electricity, it will push up the LCOH of green hydrogen. Within the CCER offset ratio range of 5% to 9%, the system simulation identifies the optimal annual operating hours of equipment at 1,920 hours. Under this condition, combined with the learning effect of proton exchange membrane electrolysis technology, green hydrogen is expected to achieve cost parity with blue hydrogen by 2030 and with gray hydrogen by 2035.

Paper ID: 216

Coupling interaction and policy co-optimization among carbon trading, green certificate and power markets

Fanyi Meng[1], Mengqi Gao[1], Yu Sun[1], Wei Zhao[2]
[1]School of Economics and Management, China University of Petroleum, Qingdao, China; [2]School of Economics and Management, Nanjing University of Science and Technology, Nanjing, China;
Email: 2483295773@qq.com

Abstract:

In recent years, China has gradually promoted the construction of various policy trading markets composed of environmental rights and interests products, with carbon emission trading (CET) and tradable green certificates (TGC) serving as important tools to realize the low-carbon transition of the power market. However, the policy effects and effectiveness under market coupling conditions remain an open question. This paper establishes a system dynamics model to analyze the internal linkages among the carbon trading market, the green certificate market, and the power market. Simulation results show that emission reduction intensity plays a dominant role in shaping carbon price dynamics and determines the long-term evolution and stability of the carbon market. In the green certificate market, RPS quota targets exert a stronger and more persistent influence on certificate prices than benchmark price adjustments, indicating that quota-based demand regulation is the primary driver of price formation. Under the market coupling scenario, power selling prices exhibit a gradual upward trend, reflecting the internalization and cost pass-through of environmental compliance costs as the coupled system approaches a mature equilibrium. In terms of policy optimization, the coupled market still faces some redundant policy effects. Based on this, this paper further proposes coupling market optimization measures to build a connecting bridge between different environmental product systems -- the mutual recognition mechanism of carbon and green certificates. The conclusion shows that this mutual recognition mechanism can optimize resource allocation and emission reduction path to a greater extent.

Paper ID: 217

Coupling time-series analysis and agent-based modeling to design staged non-price demand side management policies for durable water saving

Yacong Hu, Jinping Tian, Lyujun Chen
Tsinghua University, People's Republic of China;
Email: huyc23@mails.tsinghua.edu.cn

Abstract:

Urban water scarcity increasingly calls for demand-side management (DSM) to complement conventional supply-side engineering. However, achieving durable savings remains challenging because conservation behavior can decay, and non-price DSM measures often exhibit threshold effects and cross-policy synergies. This study proposes an integrated framework that combines time-series analysis with agent-based modeling (ABM) to simulate how non-price DSM policies—environmental education and behavioral nudges—jointly promote water-saving behavior.

High-resolution dormitory meter data from a leading university were analyzed to extract baseline consumption trends, periodicities, and holiday effects. These empirically derived patterns were translated into behaviorally grounded rules for agents in the ABM, where individuals reversibly switch between water-saving and non-water-saving states through social diffusion. The calibrated model reproduced observed campus dynamics with high fidelity ($R^2 = 0.96$).

Results show that education-only and nudge-only interventions deliver short-term reductions but regress toward a low-level equilibrium due to an endogenous ~15% reversion tendency. In contrast, a combined strategy activates an ordered cascade: high-quality education first seeds early adopters and generates a conservation signal that is subsequently amplified by nudges across the social network, driving a system-wide shift toward water conservation. Across adoption stages, the combined strategy reduced per-capita water use by 1.8%–10.7% and increased the share of water-saving students. When the initial non-water-saving ratio is 70%, adding nudges expands the feasible intervention space by 65.3%, with behavioral tipping points shaped more by education effectiveness than by coverage. Sensitivity analysis (Hornberger–Spear–Young) supports the robustness of these findings.

This transferable framework provides a roadmap for designing staged, synergy-aware DSM portfolios to achieve durable water savings and inform broader demand-side resource conservation contexts.

Paper ID: 218

Trustworthy AI for life cycle assessment: evidence grounded inventory curation with alignment and validation

Huimin Chang[1], Jing Guo[2], Nan Li[3], Hang Yang[3], Chuke Chen[3], Jianchuan Qi[3], Qing Li[4], Ming Xu[3]
[1]TianGong Think Tank, Research Institute for Environmental Innovation (Suzhou) Tsinghua; [2]School of Management Science and Engineering, Beijing Information Science & Technology University; [3]School of Environment, Tsinghua University; [4]PetroChina Planning & Engineering Institute;
Email: huimin.chang@tsinghua-riet.com

Abstract:

Life cycle assessment increasingly integrates life cycle inventory information from heterogeneous sources, including technical reports, spreadsheets, and model exports. Converting these inputs into interoperable unit process datasets requires consistent flow identification, unit handling, and metadata specification, while maintaining traceability and standards conformance. This presentation describes a framework for AI assisted inventory curation that couples language model based structuring with deterministic alignment and validation.

The framework supports two entry modes. For unstructured technical text, a language model is used to generate a structured representation of unit process metadata and exchanges, with fields intended to preserve provenance and support subsequent review. For structured JSON LD exports from LCA tools, the workflow reconstructs and normalizes process information and exchanges to a common dataset schema. In both modes, exchanges are mapped to candidate reference flows through search based matching and explicit alignment policies. The resulting datasets are then checked for conformance against the TianGong LCA data standard (TIDAS) through automated validation rules prior to publication.

The framework is implemented as a modular, stage based workflow that outputs intermediate artifacts to enable inspection, editing, and repeated validation. We discuss how separating model generation from rule based verification supports auditable use of AI in LCA, and how retrieval over domain knowledge can be incorporated to constrain extraction and reduce ambiguity. The approach provides a foundation for systematic evaluation of AI assisted inventory curation and for integration into database development pipelines that require repeatability and standards compliance.

Paper ID: 223

Pathways to forestry carbon sink value realization: Evidence from Guangxi plantations, China

Muqi Diao[1], Yu Liu[2]
[1]College of Economics and Management, China Agricultural University, Beijing 100083, China; [2]College of Urban and Environmental Sciences, Peking University, Beijing 100871, China;
Email: dmq@cau.edu.cn

Abstract:

Realizing the value of forestry carbon sinks is critical for transforming ecological assets into economic benefits under China's dual carbon neutrality goals. Guangxi possesses abundant forest resources with substantial carbon sequestration potential, yet faces challenges including limited carbon sink projects, pricing difficulties in carbon markets, and low stakeholder participation. These stem from uncertainties regarding suitable afforestation land, carbon sequestration efficacy across tree species, and fluctuating abatement costs. This study focuses on plantation forestry carbon sink value realization in Guangxi, employing empirical analysis and integrated modeling frameworks comprising environmental factor overlay models, carbon accounting models, and afforestation feasibility models.

Our findings reveal that shrubland constitutes the largest suitable afforestation area (19,197 km²), while sparse woodland, other forestland, and grassland exhibit distinct potentials. Soil carbon stocks demonstrate continuous increases from 2020 to 2060 across three primary species: Eucalyptus, Masson pine, and Chinese fir. Eucalyptus exhibits the strongest sequestration capacity with slow initial growth followed by acceleration; Masson pine shows steady growth with later deceleration; Chinese fir displays slow initial growth with subsequent acceleration. Carbon abatement costs are initially high but exhibit decreasing marginal costs as project scale expands.

Based on these findings, we propose strategic pathways including optimizing spatial resource allocation across land use types, addressing policy implementation variations among tree species, and establishing cost-sharing mechanisms among stakeholders with enhanced policy support. This study quantifies carbon sequestration dynamics and abatement costs in Guangxi's plantation forests, providing targeted recommendations for value realization pathways. Future research should establish long-term monitoring systems, refine model architectures, and expand research scope to advance forestry carbon sink studies, ensuring scientific project implementation and promoting sustainable regional ecological development.

Paper ID: 224

Carbon, water and land benefits of valorizing food loss and by-products into single-cell protein in China

Yujun Wei[1], María Rodríguez Sánchez[1], Xuexian Li[2], Huub Rijnaarts[1], Wei-shan Chen[1]
[1]Environmental Technology group, Wageningen University, Wageningen, The Netherlands; [2]National Academy of Agriculture Green Development, College of Resources and Environmental Sciences, China Agricultural University, Beijing, China;
Email: yujun.wei@wur.nl

Abstract:

The food system contributes substantially to global environmental burdens, with animal protein products being major contributors to greenhouse gas emissions, water use, and land use. Converting food loss and by-products (FLB) into single cell protein (SCP) is considered as one of the promising strategies to simultaneously reduce waste of food resources and mitigate the environmental impact of animal protein production; however, how much environmental benefits SCP can provide in food system transition and how to implement it have remained unclear. Taking China as a case, this study aims to improve that clarity. A linear programming model was applied to allocate locally available FLB resources to four kinds of representative SCP production. The model was conditioned with the objectives of optimizing savings in global warming potential, water use, and land use. The results indicate that SCP production from local FLB resources could theoretically satisfy current animal-derived protein demand in China. In addition, SCP produced from FLB via submerged fermentation and directly used as protein source in human food can deliver substantial environmental benefits. Although solid-state fermentation shows higher yields and lower environmental burden, its environmental mitigation potential is limited by its restriction to a somewhat lower priority tier for reuse, namely animal feed applications. Overall, this study highlights the environmental potential of FLB-based SCP while identifying key bottlenecks still to be resolved to further enhance its practical implementation.

Paper ID: 226

Struvite recovered from anaerobic sludge digester liquors as a circular phosphorus fertilizer: process performance and agronomic validation

Dominika Sobotka, Nicole Nawrot, Bogna Śniatała, Bartosz Fiedor
Gdańsk University of Technology, Poland;
Email: domsobot@pg.edu.pl

Abstract:

Phosphorus recovery from municipal wastewater is increasingly recognized as a strategic element of circular resource management, addressing both phosphate rock depletion and the environmental impacts of phosphorus discharge. Among available technologies, struvite ($MgNH_4PO_4 \cdot 6H_2O$) precipitation offers the dual benefit of efficient phosphorus removal and the production of a valuable fertilizer.

In this study, phosphorus was recovered from anaerobic sludge digester liquors using a struvite precipitation reactor operated under optimized conditions. The process was conducted at a Mg:P molar ratio of approximately 1.0 and a pH range of 8.5–9.5, achieving phosphorus removal efficiencies of 90–99% depending on influent characteristics. X-ray fluorescence (XRF) analysis using an oxide-based calibration confirmed that the recovered struvite product was dominated by magnesium- and phosphorus-containing compounds, with MgO and P_2O_5 as the major components. Only minor amounts of CaO and K_2O were detected, while potentially toxic elements occurred at trace or below detection levels, indicating high material quality.

The agronomic performance of the recovered struvite was evaluated in a controlled pot experiment with soybean (SOY ACASSA C1). Struvite was applied as the sole phosphorus source across a dosage range of 0.5–20 g kg^{-1} soil and compared with a non-fertilized control, while conventional KH_2PO_4 fertilization served as a reference. Plant growth, above-ground biomass, phosphorus uptake, pod number, and nodulation intensity were monitored throughout the growing season. The optimal response was obtained at a struvite dose of 2 g kg^{-1} soil, resulting in the highest biomass production, plant height, pod formation, and nodulation intensity. Higher doses reduced growth and physiological performance.

The results demonstrate that struvite recovered from sludge digester liquors can function as an effective phosphorus fertilizer for soybean cultivation when appropriately dosed. The study supports the integration of struvite recovery into circular nutrient management strategies and highlights the need for field-scale validation under realistic agricultural conditions.

Paper ID: 227

Rare Earth recycling potential for China's civilian unmanned aerial vehicles in shared socioeconomic pathways

Bin Zhang[1], Wenqi Shi[1], Zhaohua Wang[2], Changqing Xu[2]
[1]School of Management, Beijing Institute of Technology, Beijing, China; [2]School of Economics, Beijing Institute of Technology, Beijing, China;
Email: 3120255087@bit.edu.cn

Abstract:

The rapid expansion of the low-altitude economy is reshaping China's civilian unmanned aerial vehicle (UAV) sector, yet the resulting surge in demand for critical rare earth elements (REEs), poses emerging resource sustainability challenges. Although prior research has focused on technological innovation and industrial growth, the intensity of UAV embedded rare earth demand and the potential for circular recovery remain underexplored, leaving a gap in sustainability-oriented system assessment. Here we develop an integrated life-cycle framework under a sustainable development pathway, coupling multi-sector market diffusion modelling, retirement dynamics simulation and critical material flow accounting to evaluate rare earth demand and closed-loop recycling potential associated with China's civilian UAV expansion from 2025 to 2050. Incorporating prospective socio-economic trajectories and technological change, we construct 72 development pathways for scenario analysis, revealing the coupling between UAV growth and rare earth supply constraints across alternative technological and institutional configurations. Our results show that China's civilian UAV fleet will remain in an accelerated growth phase over the next 25 years, reaching about 41 million units under the sustainable pathway, with cumulative rare earth demand equivalent to 356.1% of current annual domestic production capacity. Scenario analysis indicates that a business-as-usual trajectory delivers only 28.3–31.0% closed-loop self-sufficiency, insufficient to offset the supply–demand gap, whereas an optimized circular system—combining technological improvement, high collection rates and efficient recycling—can raise self-sufficiency to 56.1–62.7%, with collection system maturity exerting the strongest influence. By highlighting the limits of single-technology solutions and the need for coordinated interventions, our work provides a framework for aligning low-altitude economic growth with critical material circularity.

Paper ID: 229

Decoupled resource circularity: a framework for analyzing SDG strategic integration in East Asian manufacturing

Hyewon Do
Yonsei Univ., Korea, Republic of (South Korea);
Email: hirozuna@gmail.com

Abstract:

This study investigates the strategic structuring and governance of corporate resource circularity practices within a circular economy framework, with a specific focus on major East Asian manufacturing firms. While existing ESG assessments primarily prioritize the quantification of environmental performance, they offer limited insight into how material-level actions are structurally integrated with global sustainability initiatives such as the SDGs.

To bridge this gap, this study employs a mixed-methods research design, utilizing a purposive sample of six prominent Korean and Japanese manufacturing firms. The first stage involves a qualitative coding analysis of sustainability report narratives to categorize corporate practices across three dimensions: (1) circularity performance based on the 3R framework (Reduce, Reuse, Recycle), (2) governance mechanisms, and (3) the degree of strategic SDG integration. In the second stage, a quantitative comparison is conducted using Refinitiv ESG Environmental (E) pillar scores to examine the policy-practice gap between standardized ESG ratings and internally articulated resource management frameworks.

The findings reveal heterogeneous patterns of circular economy governance. Certain firms demonstrate substantive 3R practices and operational governance yet fail to translate these efforts into a coherent SDG-aligned strategy, resulting in a “decoupled circularity” where implementation remains at a symbolic level of strategic integration. Conversely, other firms employ the SDGs as a strategic map that synchronizes material flows, organizational controls, and long-term resource sustainability objectives. By conceptualizing the SDGs as a structural lens rather than a mere performance outcome, this study demonstrates how a mixed-methods approach can expose discrepancies between high ESG scores and actual strategic coherence in resource management. The proposed exploratory typology contributes to circular economy research by identifying archetypes of “implementation without strategy,” which conventional ESG metrics fail to detect.

Paper ID: 230

Dynamic material flow analysis of end-of-life engineered wood in Australia

Jiabao Wang[1], Mithun Biswas[1], Wen Li[1], Benoit Belleville[2]
[1]Department of Mechanical Engineering, The University of Melbourne, Melbourne, VIC 3010, Australia;
[2]School of Agriculture, Food and Ecosystem Sciences, Faculty of Science, The University of Melbourne, Melbourne, VIC 3010, Australia;
Email: jiabao.wang.1@student.unimelb.edu.au

Abstract:

While engineered wood (EW) is a critical component in building decarbonisation when used as a replacement for carbon-intensive materials like concrete and steel, the mounting volume of post-consumer EW poses substantial environmental challenges. Currently, recycling rates for EW remain low, largely due to a lack of comprehensive research regarding the availability and flow of end-of-life (EoL) materials. To address this gap, this study employs dynamic material flow analysis (d-MFA) to map the stocks and flows of Australian EoL EW. This approach provides a detailed spatial-temporal characterisation of waste volumes, product types, and geographic distribution, enabling the development of targeted management strategies. Our findings distinguish between the trajectories of non-structural and structural EW. For non-structural EW, which often contains high concentrations of formaldehyde-based adhesives that complicate material recovery, waste-to-energy (WtE) pathways, specifically incineration and pyrolysis, emerge as the most viable current treatment options. However, the results highlight a critical WtE capacity deficit across Australia. By 2050, New South Wales, Victoria, and Queensland are projected to face capacity shortfalls of approximately 496,065 tonnes, 354,936 tonnes, and 323,879 tonnes, respectively. These results underscore an urgent need for significant infrastructure expansion to manage future wood-based panel waste flows. Also, the study identifies EoL plywood as a high-value resource, capable of supplying between 30.14% and 39.82% of the wood particle demand for new particleboard production by 2050. Regarding structural EW, waste volumes for mass timber products are projected to escalate from approximately 164,442 m3 in 2050 to 471,934 m3 by 2070, driven by the sector's rapid adoption to meet 2050 carbon neutrality goals. To enhance material efficiency and support a circular economy, establishing dedicated remanufacturing plants is essential to process these emerging mass timber waste streams.

Paper ID: 231

Geometry-based CO_2 absorption estimation for urban buildings using high-density airborne laser scanning

Hiroaki Shirakawa, Yuto Nakamura, Toshiya Sugiura, Masahiro Nagao, Hiroki Tanikawa
Nagoya University, Japan;
Email: nakamura.yuto.i3@f.mail.nagoya-u.ac.jp

Abstract:

Concrete structures function as important CO_2 sinks in urban areas through carbonation reactions that absorb atmospheric CO_2. However, existing studies predominantly employ macro-scale models based on building stock statistics or material consumption, and CO_2 absorption assessments reflecting actual building geometries remain insufficient.

This study proposes a method for estimating CO_2 absorption based on measured surface areas, including roof and wall surfaces, by reconstructing three-dimensional building geometries from high-density airborne laser scanning (ALS) point clouds. Conventional ALS, being aerial survey data, captures few point clouds on building walls. However, high-density ALS enables partial acquisition of wall surface data, making it possible to incorporate wall geometries into CO_2 absorption estimates.

The ALS point clouds were sliced in the vertical direction, and building contours at each cross-section were extracted and integrated to reconstruct three-dimensional geometries. Since high-density ALS can capture point clouds on building facades, this method quantifies wall surface areas by leveraging this capability, significantly extending conventional roof-area-centered estimation approaches that have dominated previous research.

Surface areas were calculated from the reconstructed three-dimensional geometries of buildings in the target area, and cumulative CO_2 absorption was estimated by applying a carbonation volume model. Furthermore, the effects of point density and the presence or absence of facade point clouds on estimation accuracy were quantitatively evaluated, providing insights into the technical requirements for reliable geometry-based CO_2 absorption assessment.

This study advances the evaluation of CO_2 absorption by buildings on a geometry basis through three-dimensional reconstruction using high-density ALS point clouds, contributing to more refined carbon cycle assessments at the urban scale.

Paper ID: 232

Multi-metal-controlled pyrolysis degradation pathways of waste printed circuit boards for resources-efficient thermochemical recycling

Kingsley Moses, Ubong Etim, Jerosha Ifthikar, Paulo Debiagi
University of Nottingham Ningbo China, China, People's Republic of;
Email: kingsleykelechukwu.moses@nottingham.edu.cn

Abstract:

The growing concern of electronic waste generation necessitates a thorough understanding of printed circuit board (PCB) degradation to enhance thermochemical (pyrolysis) recycling strategies. This study systematically compares the thermal degradation behavior of metal-impregnated PCB (MPCB) and laminated PCB (without metals, LPCB), emphasizing the role of compositional and structural differences. The thermal degradation kinetics of LPCB and MPCB were analyzed using various methods, including thermogravimetric analysis (TG), derivative thermogravimetric analysis (DTG), in-situ diffuse infrared Fourier transform spectroscopy (DRIFTS), iso-conversional kinetic modeling, and elemental analysis via inductively coupled plasma optical emission spectroscopy (ICP-OES). The correlation of TG/DTG profiles with DRIFTS spectra enabled the identification of distinct degradation stages to specific chemical transformations, including epoxy bond cleavage and brominated flame-retardant decomposition. Iso-conversional kinetic analysis, employing Kissinger–Akahira–Sunose (KAS) and Flynn–Wall–Ozawa (FWO) methodologies, revealed distinct degradation regimes between LPCB and MPCB. LPCB showed limited conversion ($\alpha \leq 0.20$) and displayed near-zero or negative apparent activation energies, indicating non-Arrhenius behavior governed by structural relaxation. In contrast, MPCB demonstrated higher conversion levels ($\alpha = 0.10 – 0.60$) with uniformly positive activation energies across the conversion range. At early conversion stages ($\alpha = 0.10–0.3$), lower activation energies (86–137 kJ/mol) suggested enhanced catalytic degradation facilitated by intrinsic metals, while higher activation energies (152–263 kJ/mol) at later stages ($\alpha = 0.4–0.6$) indicated a transition to char-dominated and diffusion-restricted mechanisms. The results of KAS and FWO analyses corroborated each other, confirming the reliability of the kinetic assessment. ICP-OES analysis revealed that MPCB contains significantly higher levels of catalytically active metals (Cu, Fe, Ni, Zn, Sn, and Pb) than LPCB, further establishing that MPCB degradation is influenced by the combined effects of multiple intrinsic metals rather than individual metal contributions. This study provides a composition-resolved, system-level kinetic framework for understanding MPCB thermal degradation, vital for improving pyrolysis recycling processes and fostering sustainable resource recovery within the circular economy of electronic waste.

Paper ID: 236

Beyond laundry: Dynamic material flow modelling of microplastic fibre emissions from synthetic textile production in China

Mithun Kumar Biswas[1], Haiwei Zhou[1], Liuhua Peng[2], Wen Li[1]
[1]Faculty of Engineering and Information Technology, The University of Melbourne, Melbourne, VIC 3010, Australia; [2]School of Mathematics & Statistics, The University of Melbourne, Melbourne, VIC 3010, Australia;
Email: mithunkumar.biswas@student.unimelb.edu.au

Abstract:

Microplastic fibre (MPF) pollution from synthetic textiles is an escalating global concern with potential long-term impacts on ecosystems and human health. Existing system-wide inventories primarily focus on household laundering, mostly concentrated in developed countries, while production-phase emissions, mainly occurring in the Global South, remain insufficiently quantified. This imbalance limits accurate estimation of total life-cycle MPF releases and obscures the true scale of emissions from the synthetic textile industry, thereby constraining effective mitigation and exposure assessment. Addressing this gap, this study presents the first comprehensive dynamic material flow model designed to quantify MPF emissions from synthetic textile production systems, integrating detailed production processes, stage-specific emission factors, and pathway-resolved releases to air, water, and soil. China, the world's largest producer of synthetic fibres and textiles, is used as a case study. Results indicate that 1542.0 ± 8.56 kilotonnes (kt) of MPFs were cumulatively released between 1992 and 2024. Airborne emissions accounted for approximately 61% of total releases, with nearly half originating from synthetic fibre production alone. Polyester (PET) dominated the emission profile, contributing 89% of total MPFs. Despite China's role as the largest exporter of synthetic textiles, 62% of total MPF emissions were associated with production for domestic consumption. Spatial analysis reveals strong regional concentration, with Shanghai, Jiangsu, Fujian, and Zhejiang collectively contributing more than 85% of total emissions. Coupling the emission inventory with transport and fate modelling indicates that terrestrial soils represent the primary environmental sink, accumulating 59% of total MPFs by 2024, followed by marine environments at 26%. The model framework in this study is adaptable to other regional textile systems and provides a robust basis for production-phase MPF mitigation strategies. By quantifying previously overlooked production-related emissions, this study establishes a critical foundation for improved exposure assessment, environmental risk evaluation, and evidence-based policy development addressing microplastic pollution from synthetic textiles.

Paper ID: 237

Contribution of global realizable wind potential to climate targets

Tianyu Jia, Yuqiao Lan, Yuewen Luo, Changqing Xu
Beijing Institute of Technology, China, People's Republic of;
Email: jty_69@163.com

Abstract:

Wind power is a critical zero-carbon resource, yet existing research often relies on low-frequency data that fails to support flexible grid allocation. Current assessments frequently overlook onshore-offshore synergy and future environmental benefits of grid greening, leaving the actual contribution of wind power to specific climate targets unclear. This study constructs a high-resolution global hourly wind power capacity factor dataset to evaluate the realizable potential of onshore and offshore wind energy. On this basis, the stability of combined onshore-offshore power output is assessed using smoothing effects and ramp rate reduction metrics, while life cycle assessment and dynamic decarbonization scenarios are utilized to determine wind energy's contribution to remaining carbon budgets for 1.5°C and 2.0°C targets. Results indicate that onshore-offshore synergy significantly reduces system volatility in regions like China and the USA, with ramp rate reductions exceeding 50% in top-performing nations. Furthermore, global wind resources possess the physical capacity to support complete power system decarbonization. Under a strict 1.5°C scenario, wind energy can account for approximately 45% of the remaining carbon budget, representing six times its relative contribution to the 2.0°C goal. These findings provide a scientific basis for energy transition and highlight the importance of wind power in achieving global climate goals.

Paper ID: 239

Feasibility-first process network synthesis for circular cotton textile waste recovery using P-graph

Joanna Tess Masilungan-Manuel[1,2], John Frederick Tapia[1], Raymond Tan[1]
[1]De La Salle University, Philippines, Department of Chemical Engineering; [2]Philippine Textile Research Institute, Department of Science and Technology;
Email: joanna_manuel@dlsu.edu.ph

Abstract:

Cotton textile waste recovery is commonly optimized within assumed network configurations, despite strong dependence on material compatibility, processing limits, and resource constraints. This study applies the P-graph framework for process network synthesis to enumerate all structurally feasible cotton textile waste recovery networks prior to any economic or environmental optimization. Four waste stream (side-stream, pre-consumer, post-consumer, and throwback cotton waste) are evaluated against mechanical recycling, chemical recycling, nonwoven processing, and waste-to-energy technologies under capacity and other constraints. The results identify a small and bounded set of optimal and near-optimal recovery configurations, demonstrating that cotton textile recovery requires decisions pertaining not only on resource allocation but also network structure configurations. Distinct recovery topologies are generated from using the P-graph's solution structure generation (SSG) algorithm. Then, optimal flows are determined in each network subject to economic and environmental constraints and redundant networks are eliminated via accelerated branch-and-bound (ABB) algorithm. The findings imply that recycling targets, technology deployment, and infrastructure investment in textile recovery pathway planning should be first aligned with structurally feasible recovery configurations. Variation in recycling rates are observed in each configuration, providing insights on the range of networks that can be adopted depending on the regional capability. By establishing the structural limits of cotton textile waste recovery systems, this study provides a feasibility-first foundation for realistic optimization, infrastructure planning, and circular textile system development.

Paper ID: 240

Applying the plastic transition meta-framework to study system dynamics and impacts of bioplastic materials in designed closed-loop drinking cup systems

Yme Van Lith[1], Marieke Brouwer[2], Ulphard Thoden van Velzen[2], Judith Van Leeuwen[1], Wei-Shan Chen[1], David Strik[1]
[1]Wageningen University & Research; [2]Wageningen Food & Biobased Research;
Email: yme.vanlith@wur.nl

Abstract:

The environmental and societal impacts of plastics demand a transition towards a more sustainable plastic system. Yet, the complexity of plastic value chains and the fragmented approaches, hinder systemic understanding and effective interventions. Holistic transition studies are needed to capture interconnected sustainability challenges and system dynamics. This study introduces the Plastic Transition Meta Framework (Plastic TMF) as a comprehensive and interdisciplinary approach, designed to support the analysis of transitions toward sustainable plastic economies. The framework is developed through a PRISMA-based literature review and integration of established transition and systems frameworks. It operationalizes 156 components and 221 indicators across six interconnected subsystems: technological, socioeconomic, ecological, driving forces, societal goals, planned interventions. By distinguishing status quo, system dynamics and transitions, the framework reveals circular transition barriers and enables evaluation of interventions.

One core intervention in the plastic transition are polyhydroxyalkanoate (PHA) materials. This biobased, biodegradable polymer is built by microorganisms and has potentials in renewable feedstocks and recycling. Packaging, cups, textiles are emerging PHA products. The framework's applicability was demonstrated through a case study evaluating the social, technological, and environmental impact of large-scale PHA cup adoption in Dutch closed-loop festival systems. Intervention scenarios were designed and modeled to assess sustainability outcomes. These scenarios explore new PHA pathways, involving renewable feedstocks and advanced bioplastic recycling technologies. Using mixed-methods, including 21 interviews, MFA modeling, and indicator analysis, the study demonstrates how the framework advances systemic resource transition analysis. Results show the significance of interconnectivity between waste and renewable feedstocks, value chain collaborations, existence of > 20 barriers and enablers, and technical potential of scaling biochemical recycling technologies. The Plastic TMF application highlights the PHA cups' status and transition potential. Furter transition design with stakeholders could facilitate PHA use in society. The framework offers a scalable approach integrating MFA and performance assessment for (bio)plastic value chains.

Paper ID: 243

Pyrolysis and desulfurization of waste tires for recarburization in steelmaking

Jaeuk Myeoung, Sun-Joong KIM
Chosun university, Korea, Republic of (South Korea);
Email: ksjoong@chosun.ac.kr

Abstract:

Landfilling and incinerating plastic and polymer wastes cause severe environmental issues, such as soil pollution and toxic dioxin emissions. Carbonization is paying attention as a key technology for carbon neutrality, converting waste into valuable carbonaceous materials. On the other hand, achieving carbon neutrality by 2050 requires developing alternative carbon sources for steelmaking, especially for Electric Arc Furnace operations. This study investigated the pyrolytic and desulfurization characteristics of waste tires and evaluated their recarburization efficiency as a novel carbon resource in steelmaking. Increasing the temperature to 1273 K enhanced fixed carbon by removing volatiles, however, sulfur enrichment occurred due to the formation of ZnS. This issue was addressed by introducing Na2CO3 and CaC2 as desulfurizing additives, effectively reducing the sulfur content through the decomposition of ZnS. Notably, the carbon resource produced in this study demonstrated a high recarburization efficiency exceeding 90% during molten steel recarburization experiments. In summary, the findings substantiate that waste tires, when processed under optimized pyrolytic and desulfurization conditions, represent a high-performance, sustainable alternative to metallurgical coke in electric arc furnace (EAF) operations.

Paper ID: 244

Topographic constraints on the spatial patterns and driving mechanisms of urban building material stocks: evidence from the Sichuan-Chongqing Region

Zezhuang Liu[1], Jian Sun[1,2], Xiaofeng Gao[1], Yilu Gu[1]

[1]Key Laboratory of the Three Gorges Reservoir Region's Eco-Environment, Ministry of Education, College of Environment and Ecology, Chongqing University, China; [2]School of Civil and Environmental Engineering, Nanyang Technological University, Singapore;

Email: cquhjlzz@163.com

Abstract:

Rapid urbanization has led to a massive accumulation of building material stocks (MS), yet the physical constraints of topography on these stocks remain poorly understood. Here we assess the spatial patterns and driving mechanisms of building MS across the Sichuan-Chongqing Region using high-resolution mapping and Multiscale Geographically Weighted Regression. We show that the total MS in the region amounts to 5.67 Gt, with distinct morphological divergences dictated by terrain. While plain-dominated cities (e.g., Chengdu) exhibit concentric spreading, mountain-constrained cities (e.g., City Chongqing) display fragmented, polycentric structures. Notably, we identify a U-shaped relationship between material intensity and slope in mountain cities, driven by high-density commercial cores on flat terrain and engineering-intensive construction on steep gradients. Our results indicate that while economic centrality drives stock accumulation in plain regions, mountain urbanization is governed by a core-periphery dualism. Capital investment overrides topographic costs in city centers, whereas physical geography strictly limits development in the periphery. We underscore that sustainable urban resource management requires differentiated strategies that strictly account for local geographic constraints.

Paper ID: 249

A global facility-level assessment of data center water consumption and scarcity footprints

Yuqiao Lan, Changqing Xu, Tianyu Jia, Yuewen Luo
Beijing Institute of Technology, China, People's Republic of;
Email: yuqiao.l@bit.edu.cn

Abstract:

Driven by the rapid expansion of digital infrastructure, data centers are becoming an emerging source of water consumption and localized water scarcity risks. While environmental discussions have largely focused on electricity use and carbon emissions, their water impacts remain insufficiently quantified, especially from a facility-level and water-scarcity perspective. This study presents a global point-source assessment of data center direct water consumption and water scarcity footprints. We integrate public data center platforms, corporate disclosures, PDF documents and descriptive texts to construct a facility-level dataset covering more than 13,000 data centers worldwide. Combining facility power, utilization, cooling technology, climate-driven PUE/WUE estimates and gridded water scarcity characterization factors, we quantify water consumption and scarcity footprints across global, national and facility scales. Results show that global data centers consume approximately 520.28 TWh of electricity annually, leading to 706.52 million m^3 of on-site water consumption and 17.94 billion m^3-eq of water scarcity footprint. These impacts are spatially concentrated, with a small share of high-impact facilities contributing disproportionately to global water scarcity footprints. Facility-level PUE/WUE parameterization substantially changes water impact estimates compared with regional-average assumptions, indicating that aggregated parameters may obscure facility heterogeneity and misidentify risk hotspots. Future scenarios show that data center expansion will increase water pressure, while operational optimization, advanced liquid cooling, higher server utilization, reclaimed water substitution and water-sensitive siting can reshape future outcomes. Combining facility-side efficiency improvements, alternative water sourcing and spatial siting optimization provides the greatest mitigation potential and may offset the projected growth in water scarcity footprints.

Paper ID: 250

Tripling of metal requirements in China's electric grid over the past two decades

Kaipeng Ren[1], Weichen Wang[1], Xu Tang[2], Jakob Willerström[3], Mikael Höök[3]
[1]College of Science, China University of Petroleum(Beijing), China, People's Republic of; [2]School of Economics and Management, China University of Petroleum(Beijing), China, People's Republic of; [3]Natural Resources and Sustainable Development Programme, Department of Earth Sciences, Uppsala University, Uppsala, Sweden;
Email: kaipeng_ren@cup.edu.cn

Abstract:

The electric grid constitutes the foundational infrastructure for power transmission, end-use electrification, and national energy security. Driven by ambitious development goals and rapid technological advancement, China has established the largest and most complex electricity grid in the world. Despite its scale and strategic importance, the associated metal requirements remain insufficiently examined, constraining effective management of raw material supply, in-use metal stocks, and end-of-life waste streams. In this study, we conduct a comprehensive assessment of base metal requirements for China's electric grid at the provincial level over the period 2004–2024.

The material flows of copper (Cu), aluminum (Al), and iron (Fe) in China's electric grid are quantified using a dynamic material flow analysis (MFA) framework, supported by a self-compiled metal intensity dataset. The results indicate that: (1) metal intensities of cables have increased in response to rising electricity demand, highlighting potential risks of metal scarcity and associated environmental pressures; (2) by 2024, approximately 2.45 million km of electric cables require in-use stocks of 42 Mt of Cu, 30 Mt of Al, and 20 Mt of Fe—representing a 3.3–3.7-fold increase compared to 2004 levels; and (3) the top eight provinces account for approximately 43–49% of the national total metal stock in 2024, revealing pronounced spatial disparities.

These findings underscore the need for province-specific strategies on recycling and end-of-life management, alongside strengthened interregional technological cooperation. Future grid expansion and infrastructure planning should explicitly incorporate material considerations to balance ambitious development targets with resource sustainability and regional equity.

Paper ID: 251

Leveraging large language model for anaerobic digestion process prediction: a two-stage fine-tuning strategy with literature and plant-specific data

Yi Zhang, Zongguo Wen
Tsinghua University, China, People's Republic of;
Email: z-y24@mails.tsinghua.edu.cn

Abstract:

Traditional machine learning (ML) exhibited limited generalization in cross-domain performance prediction for anaerobic digestion (AD) process, which was attributed to their inability to interpret multi-type data. To leverage the distinctive capability of large language model (LLM) to collaboratively process text and numerical data, we developed and implemented an innovative two-stage fine-tuning LLM strategy. First, the model was trained on a large-scale literature data corpus to establish domain knowledge and transfer learning capabilities. Subsequently, scene adaptive fine-tuning was conducted using plant-specific data to ensure the practical application precisely. The experimental results show that this hierarchical training strategy significantly enhances the predictive performance and generalization ability of the model. The LLM trained by literature achieved an R2 of 0.94 on a multi-source test set, which was 13% higher than the optimized conventional ML model. Compared with LLM trained from scratch, the prediction accuracy of LLM trained by literature has increased by 53%, and the training loss has been reduced by 50%, which reduced reliance on large-scale scene-specific labeled data. To clarify the underlying mechanism, ablation studies confirmed that the non-numerical textual context played a key role in model training, serving as a core driver that guided the model to internalize process logic and enhance generalization. Therefore, this study provided a feasible technical pathway to address the common challenges of data scarcity and diverse scenarios in AD system, which held significant theoretical value and practical significance for promoting the deployment of artificial intelligence in the field of bioenergy.

Paper ID: 252

A global stage model of anthropogenic material stocks and economic capital co-evolution from germination to decoupling

Jian Sun[1,2], Zezhuang Liu[1], Xiaofeng Gao[1], Yilu Gu[1]
[1]Chongqing University, People's Republic of China; [2]School of Civil and Environmental Engineering, Nanyang Technological University, Singapore;
Email: sunjian143687@163.com

Abstract:

Anthropogenic material stocks (MS) underpin human well-being but drive environmental burdens. However, their long-term global evolution and distribution remain poorly understood. To address this gap, we reconstructed historical MS (1970–2020) and projected future trajectories to 2100 for 157 countries using Random Forest models under Shared Socioeconomic Pathways. Our results show a massive expansion where global MS tripled to 1,146 Gt by 2020 and is projected to reach up to 4,000 Gt by 2100. Crucially, inequality persists, with a Gini coefficient near 0.5 even as income gaps narrow. Mechanism analysis reveals that energy systems and urban land area drive 47% of stock accumulation. Based on these dynamics, we identified six development stages from germination to decoupling. While true decoupling is rare today, projections suggest over 15% of countries could achieve it by 2100. We conclude that realizing this transition requires a strategic shift from expansion to management, leveraging compact urbanization and circularity to sustain services.

Paper ID: 253

Fluorine recovery from low-concentration fluorine wastewater by flow-electrode capacitive deionization and fluid bed crystallization (FCDI-FBC): preconcentration and high-quality fluorite pellets formation

Jing Yang, Hui Gong
Tongji University, China, People's Republic of;
Email: 18032575587@163.com

Abstract:

Fluorine (F), critical for various industries, faces resource scarcity due to limited reserves of its primary source, fluorite (CaF_2). While fluorine-containing wastewater from industrial processes represents a valuable potential resource, recovering fluorine from low-concentration wastewater remains challenging. This study introduces a cyclic "preconcentration + recovery" system combining flow-electrode capacitive deionization (FCDI) and fluidized bed crystallization (FBC) to address this gap. FCDI preconcentrates fluorine ions into high-concentration brine, and FBC facilitates the formation of high-purity fluorite crystals. Experimental parameters influencing FCDI efficiency - such as influent fluoride concentration, electrode solution composition, and flow rate - were systematically evaluated. Additionally, the cyclic operation was modeled to enhance the whole recovery rate across multiple cycles. The experimental results demonstrated that FCDI achieves an 83.90% fluoride removal rate under optimal conditions with energy-efficient operation. FBC produces fluorite crystals of up to 97.20% purity, classified as acid-grade. The integrated FCDI-FBC system achieves a fluoride recovery rate of 64.40% in single operation mode, with further improvements in cyclic mode. The proposed system offers a sustainable and economically feasible solution to fluorine recovery from low-concentration wastewater, representing a significant step toward the sustainable utilization of non-renewable fluorite resources.

Paper ID: 254

Unlocking biomass energy potential: a national-scale material flow analysis of Malaysia's palm oil waste

Zheng Hao Leong, Zongguo Wen
Tsinghua University, China, People's Republic of;
Email: liangzh24@mails.tsinghua.edu.cn

Abstract:

The global transition towards a circular economy relies heavily on optimizing agricultural biomass, yet complex flows of supply chains often conceal the true resource potential. In Malaysia, the palm oil industry serves as the national economic backbone and a massive potential source of renewable biomass. However, a critical lack of integrated, system-wide data currently hinders effective waste management and the full realization of the National Biomass Action Plan (NBAP) of Malaysia. This study addresses this gap by utilizing material flow analysis (MFA) to systematically quantify the annual generation, transformation, and distribution of waste streams within the Malaysian palm oil industry, specifically palm oil mill effluent (POME), palm kernel shell (PKS) as well as palm fibre (PF). By establishing rigorous system boundaries, this study develops a comprehensive national-scale material flow model that tracks raw fresh fruit bunches (FFB) through various industrial processing stages into crude products, refined products and interdependent waste streams. The results not only quantify the vast overall potential of biomass energy recovery but specifically reveal that approximately 147,000 to 159,000 tonnes of coal equivalent (tce) of biomass energy could have been recovered annually between 2019 and 2023 from POME alone via biogas treatment facilities. Fundamentally, this study develops a quantitative framework which establishes a material flow model, assisting in providing data-driven insights for policymakers and investors, bridging the gap between current waste generation and the strategic implementation of waste management and circular economy model in the global agriculture industry.

Paper ID: 255

Manufacturing of lfp latp composite cathode for solid state battery applications via conventional processing methods

Mochamad Rafi Nabhan Nasrullah, Bentang Arief Budiman
Institut Teknologi Bandung, Indonesia;
Email: 23124044@mahasiswa.itb.ac.id

Abstract:

The development of All-Solid-State Batteries (ASSBs) has garnered considerable attention owing to their superior safety, enhanced thermal stability, and potential for higher energy density compared to conventional lithium-ion batteries utilizing flammable liquid electrolytes. In this study, the fabrication and physical characterization of a composite cathode comprising $LiFePO_4$ (LFP) and $Li_{1.3}Al_{0.3}Ti_{1.7}(PO_4)_3$ (LATP) solid electrolyte were systematically investigated for ASSB applications. The composite powders were prepared using a powder metallurgy route involving milling, homogenization, sieving, and uniaxial compaction under applied pressures of 100 MPa and 400 MPa. Subsequently, a cold sintering process (CSP) was conducted at 120 °C to promote densification while minimizing energy consumption, reducing processing time, and enhancing interfacial compatibility between the cathode and solid electrolyte phases. The densification behavior of the fabricated pellets was evaluated using the Archimedes method to determine bulk and relative densities. Surface properties were characterized through roughness measurements (Ra and Sa), whereas microstructural features and grain size distribution were analyzed using digital microscopy. Furthermore, the surface condition of the punch and die was examined to assess its influence on compaction quality and potential defect formation during pellet fabrication. The results demonstrate a strong dependence of densification and microstructural uniformity on compaction pressure, with higher pressure significantly improving relative density and structural homogeneity of the LFP–LATP composite pellets. Improved densification directly contributes to enhanced mechanical integrity of the cathode structure, which is critical for achieving stable electrochemical performance. Overall, this study provides valuable insights into optimizing processing parameters for ASSB cathode fabrication and supports the advancement of safer, thermally stable, and mechanically robust solid-state battery systems.

Paper ID: 258

Global spillover effects of mitigation policies: implications on China's carbon neutrality

Xinbei Li, Yu Liu, Xinran Zhao
College of Urban and Environmental Sciences, Peking University, People's Republic of China;
Email: lixinbei@pku.edu.cn

Abstract:

Regional heterogeneity in climate mitigation policies triggers cross-border spillovers that can undermine the efficacy of national strategies. Despite this, global climate governance remains predominantly production-based, frequently overlooking the systemic risks posed by policy asymmetries. As the world's largest developing economy, China is uniquely vulnerable to these international spillovers, necessitating a rigorous assessment of their impact on domestic carbon neutrality pathways. Focusing on China, this study evaluates how international spillovers influence mitigation outcomes, economic costs, and the feasibility of the 2060 carbon-neutrality target. Our findings indicate that spillovers reduce the probability of achieving carbon neutrality from 67% to 63%, rendering 729 previously viable policy pathways ineffective. These failed trajectories are primarily characterized by low-intensity carbon pricing and insufficient deployment of renewable energy and electrification. Notably, by 2060, while spillovers are projected to reduce aggregate economic losses by 28.6-85.8 billion USD, they simultaneously drive up unit abatement costs by 19%-55%, highlighting a critical trade-off between macroeconomic burden and mitigation efficiency. We identify a coordinated portfolio, combining low-intensity carbon pricing with high-intensity renewable energy and electrification, as the most resilient strategy. This mix ensures carbon neutrality at an average cost of 161 USD/t CO_2, maintaining both mitigation stability and long-term economic viability.

Paper ID: 259

Spatiotemporal evolution and driving mechanisms of urban ecological resources in China's typical regions under sustainable energy transition

Peize Wu, Sha Chen
Key Laboratory of Beijing on Regional Air Pollution Control, Department of Environmental Science and Engineering, Beijing University of Technology, Beijing 100124, China;
Email: wprimoz@emails.bjut.edu.cn

Abstract:

Energy transition is a key in addressing climate change, yet its pathways vary substantially across different regions in China due to differences in ecological resource endowments and development stages. Understanding the spatiotemporal heterogeneity of urban ecological resources is crucial for coordinating sustainable energy transition and regional sustainability. This study developed an integrated analytical framework (Heterogeneity of Ecological Resource Status, HERS) to analyze the evolution and driving mechanisms of ecological resource status in China's typical regions under sustainable energy transition. Comprising 22 indicators systematically selected from the perspectives of ecological resources, environment, and socioeconomic development, a multidimensional Pressure-State-Response (PSR) framework was developed to evaluate the urban ecological resource status. And the Ecological Resource Status Index (IERS) was calculated using combined weighting (Analytic Hierarchy Process and CRITIC method, AHP-CRITIC). The coupling coordination degree (CCD) model was employed to diagnose the coordination heterogeneity within this complex system. Subsequently, spatial autocorrelation analysis and spatiotemporally geographically weighted regression (GTWR) were applied to investigate the spatiotemporal evolution patterns of urban ecological resource status and to elucidate the driving mechanisms underlying the energy transition process. Using the HERS framework, a comparative analysis was conducted on 60 cities across two ecologically contrasting regions in China from 2013 to 2022: the ecologically fragile, carbon-locked Coal Triangle region and the ecologically sensitive, rapidly growing Sichuan-Chongqing region. The results showed the Coal Triangle exhibits significantly lower IERS and persistent "high-pressure, weak-response" system imbalance. IERS presented distinct spatial "cold spots" (northern Shaanxi, eastern Ningxia) and "hot spots" (Chengdu-Chongqing urban agglomeration). The negative impact of secondary industry on IERS showed strong spatiotemporal non-stationarity—remaining severe in resource-based cities yet weakening in regions with advanced industrial transformation. The results can provide scientific basis and policy recommendations for regional green low-carbon transformation and high-quality sustainable development, maximize the advantages of the city's ecological resources.

Paper ID: 260

Shredder blade design for lithium-ion battery recycling: optimizing thickness via validated finite element simulations

Hafizh Muhammad Faza[1], Bentang Arief Budiman[2], Zela Tanlega Ichlas[3], Richard Diaz Alorro[4]

[1]Department of Mechanical Engineering, Institut Teknologi Bandung, Indonesia; [2]Faculty of Mechanical and Aerospace Engineering, Institut Teknologi Bandung, Indonesia; [3]Faculty of Mining and Petroleum Engineering, Institut Teknologi Bandung, Indonesia; [4]School of Mines: Minerals, Energy and Chemical Engineering, Curtin University, Australia;

Email: 23124032@mahasiswa.itb.ac.id

Abstract:

In the recycling process of end-of-life (EoL) batteries, effective material separation is essential for the recovery of valuable minerals. Mechanical shredding serves as a critical preliminary step in the recycling chain, playing a pivotal role in determining the efficiency of downstream metal recovery. This study investigates the optimization of shredder blade design, specifically blade thickness using validated Finite Element Method (FEM) simulations to control fragmentation outcomes. The research commenced with an experimental phase examining five cylindrical 18650 battery specimens characterized by distinct cathode chemistries (LFP, NCM, NCA, and LMO). Prior to destruction, the specimens underwent charging-discharging cycles to verify their State of Health (SoH) against manufacturer specifications, followed by a deep discharging process to ensure safety during the shredding process. The shredded material was sieved to measure mass retention per mesh, generating baseline experimental Particle Size Distribution (PSD) curves. Concurrently, a numerical simulation was developed with a blade geometry that exactly replicated the experimental setup. After establishing appropriate material constitutive models and boundary conditions, the initial FEM model was thoroughly validated against the experimental PSD data to ensure high simulation fidelity. Following validation, a parametric optimization study was conducted by modifying the shredder blade thickness, implementing both thicker and thinner configurations. The core analysis evaluates how these specific geometric modifications influence fragmentation behavior, tracking the shifts in the simulated PSD curves of the shredded battery fragments for each blade variation. The findings provide insights into shredder blade design, offering a validated framework for optimizing equipment parameters to maximize liberation efficiency in industrial recycling.

Paper ID: 261

WuYu-E: A domain-specific text embedding model for solid waste management

Zhixing Pan, Zongguo Wen

Tsinghua University, China, People's Republic of;

Email: pan-zx24@mails.tsinghua.edu.cn

Abstract:

The intelligent transformation of solid waste management (SWM) systems is fundamentally dependent on the profound semantic comprehension of specialized terminology, policy frameworks, and technical documentation. However, general-purpose natural language processing (NLP) models exhibit significant limitations in capturing domain-specific semantics, particularly regarding low-frequency professional vocabulary and complex policy logic, resulting in suboptimal representation quality. To address these challenges, this study developed and implemented WuYu-E, a specialized text embedding model tailored for the SWM domain. Built upon the BAAI/BGE-M3 architecture, the model integrates agent-driven data synthesis techniques to construct a high-quality dataset of 48,797 refined "query-positive-hard negative" triplets derived from a comprehensive knowledge corpus spanning eight core SWM categories. Supervised fine-tuning (SFT) was subsequently employed to enhance the model's discriminative capabilities within complex professional scenarios. Experimental results demonstrate that WuYu-E significantly outperforms the base model across all domain-specific tasks. Key improvements include a 15.5% rise in NDCG@10 for retrieval (reaching 0.946), an 87.5% surge in Pearson correlation for semantic similarity (0.465 to 0.872), a 17.3% improvement in classification accuracy (0.486 to 0.570) marking over the base architecture. Notably, WuYu-E maintains robust generalization capabilities in general retrieval tasks, effectively mitigating the risk of catastrophic forgetting. This research not only provides a high-performance semantic tool for intelligent SWM but also establishes a reproducible and scalable technical framework for constructing specialized embedding models in other vertical domains.

Paper ID: 265

Simulation modeling of carbon market expansion: pathways for decarbonization of energy-intensive industries and evolution of electricity demand

Meng-yang He[1], Tian-tian Feng[1,2,3]

[1]School of Economics and Management, China University of Geosciences, Beijing, 100083, China; [2]MOE Social Science Laboratory of Mineral Resources Security Governance, China University of Geosciences, Beijing,,100083; [3]Key Laboratory of Carrying Capacity Assessment for Resource and Environment, Ministry of Natural Resources, Beijing 100083, China;

Email: hmyyy18268467908@163.com

Abstract:

Amid the expansion of China's Carbon Emission Trading Scheme (ETS), the decarbonization of energy-intensive industries (EIIs) is operating within increasingly complex policy and energy constraints. Under the coupling of diversified policy instruments, the abatement response logic of EIIs and its deep feedback on electricity demand remain unclear, necessitating systematic quantitative evaluation. This study develops a System Dynamics (SD) model integrating carbon trading, electricity supply, and industrial mitigation subsystems. Utilizing a Stock-Flow Diagram (SFD), the model simulates the endogenous drive of multi-dimensional policy combinations on industrial abatement decisions. Through causal feedback loops, we characterize the dynamic response logic of electricity demand during the evolution of abatement measures under varied policy intensities. Simulation results indicate that varying policy intensities significantly alter the decarbonization pathways and power consumption characteristics of EIIs. The findings reveal that tightening ETS constraints, while driving down emission intensities, also triggers systemic fluctuations in electricity demand. This study quantifies the carbon price evolution and energy demand feedback under different abatement strategies, unveiling the mechanisms linking policy pressure with power load shifts. The findings provide strategic references for EIIs facing ETS expansion, suggesting that policymakers should synergize industrial abatement potential with energy security in future policy designs.

Paper ID: 267

Spatial and temporal dynamics of sewage sludge phosphorus recovery potential in the cities of Yangtze River Zone in China: Implications for regional recycling policies

Shuyan Zhou, Hui Gong
Tongji university, China;
Email: 2331334@tongji.edu.cn

Abstract:

Sewage sludge phosphorus (P) recovery presents opportunities to sustainably recycle P from cities to agriculture and alleviate global P scarcity. However, limited research explores sustainable recovery targets considering spatial-temporal variations in sludge generation and implications based on city-level local P demand. This study analyzed sludge production over 2009-2021 across 130 cities in China's Yangtze River Zone, which increased by almost 35% from 2009 to 2021. Per capita gross domestic product (GDP), influent chemical oxygen demand (COD), and per capita drainage infrastructure were identified as main significant influencing factors. City-level analysis revealed pronounced spatial-temporal disparities, with yearly sludge generation spanning five orders of magnitude (62-5.4×105 t/a). An indicator, "Potential of P recovery to local P demand", was defined, indicating the average city-level P recycle contribution increased from 5.3% to 18.9% during 2009-2021. A novel frame paradigm based on supply-demand characteristics classified cities into "P recycling supply cities" with surplus recoverable P versus "P recycling self-sufficient cities". City-specific dynamics and possibilities of broader "city clusters" to match supply and demand should be considered for policies implement. Recovering P from livestock manure and kitchen waste alongside sludge can further strengthen urban P cycles. This study provides novel city-scale analysis and strategic considerations for regional sludge P recycling policies in China and beyond.

Paper ID: 270

Cradle-to-gate carbon emissions of battery-grade nickel and cobalt cathode materials

Yanhao Wei[1], Min Liu[1], Fang Wang[1], Xuexing Pan[2], Guangliang Lin[2], Xin He[3], Daniel De Castro Gomez[4], Omar Hurtado Perez[4], Ye Wu[1,5,6,7], Shaojun Zhang[1,5,6,7]

[1]School of Environment, Tsinghua University, Beijing 100084, P. R. China; [2]Contemporary Amperex Technology Co., Limited, No.2 Xingang Road, Ningde, Fujian, [3]52100, China; 3Aramco Americas, Aramco Research Center–Detroit, 46535 Peary Ct., Novi, MI 48377, USA; [4]Technology Strategy and Planning, Saudi Aramco, P.O. Box 62, Dhahran 31311, Saudi Arabia; [5]Key Laboratory of Sources and Control of Air Pollution Complex, Ministry of Ecology and Environment, Beijing, 100084, P. R. China; [6]State Key Laboratory of Regional Environment and Sustainability, Beijing 100084, P. R. China; [7]Beijing Laboratory of Environmental Frontier Technologies, School of Environment, Tsinghua University, Beijing, 100084, China; Email: weiyh24@mails.tsinghua.edu.cn

Abstract:

The electrification of transportation has led to a surge in the demand for lithium-ion batteries, which would use nickel sulfate and cobalt sulfate as key cathode materials for lithium nickel manganese cobalt (NCM) batteries. The sustainablity of these battery materials receives extensive concern due to relevant regulations across the world. China is the leading country in refining process for battery-grade nickel and cobalt chemicals. Existing models and studies often overlook the variety of upstream products, the investigation of Chinese refining activities and the co-production of nickel and cobalt chemicals. This study integrates enterprise data from China's local refining sector with reported data on upstream mining and primary processing for nickel sulfate (NiSO4) and cobalt sulfate (CoSO4) producing, providing a comprehensive evaluation of their carbon footprint characteristics of typical production routes. The results show that the average carbon footprint levels of NiSO4 and CoSO4 are 5.57 tCO2/t and 5.07 tCO2/t, respectively. Energy consumption is the dominant driver of emissions, while ore grade, production scale, and fuel type also exert significant influence, reflecting the intrinsic properties of intermediates and material flows. Within the industrial chain, the processing stage is the primary contributor to emissions. The wide variation in hydrometallurgical routes can lead to greater impacts on the carbon footprint of NCM811 and NCM523 batteries than pyrometallurgical routes. High-nickel NCM is a trend, but hydrometallurgical routes are carbon-intensive, leading to 6% more emissions for NCM811 batteries than for NCM523 batteries, and pyrometallurgical routes are resource-constrained. This analysis identifies opportunities to mitigate carbon emissions through technology shifts, cleaner energy systems, and material recycling, supported by improved extraction methods, renewable-based grids, and recycling offsets. Together, these measures are projected to achieve 8% and 15% emission reductions in NiSO4 and CoSO4 production by 2035, and recycling has greater potential for emission reduction.

Paper ID: 271

The decline in CCS costs facilitated low-carbon energy transition in China

Zezheng Li, Liu Yu, Zhengxian Zhang
Peking University;
Email: lizezheng122@163.com

Abstract:

Carbon Capture and Storage (CCS) is a critical technology for achieving China’s carbon neutrality goal, yet its deployment scale and economic feasibility are highly dependent on technological progress and spatial source-sink matching conditions. Existing integrated assessment models often inadequately characterize the source-sink structure and transportation constraints of CCS, making it difficult to accurately reflect the impacts of regional differences and infrastructure costs on energy transition pathways. This study develops a facility-level, integrated onshore-offshore CCS source-sink matching optimization model to generate regional and technology-specific abatement cost curves. These curves are then embedded into the provincial-level China version of the Global Change Analysis Model (GCAM-China) to systematically assess the impacts of CCS technological progress on China's low-carbon energy transition pathways and system costs. The results indicate that: (1) The decline in CCS technology costs helps reduce China's energy transition costs and alleviates long-term abatement cost pressure, with particularly pronounced effects in Central China and the southeastern coastal provinces. (2) Lower CCS costs increase the share of fossil fuels retained in the medium- to long-term energy mix, providing critical support for deep decarbonization, especially in the industrial sector. However, in the power sector, the substitution effect with renewables is limited, and the two exhibit a structural complementary relationship. (3) CCS technological progress helps mitigate systemic transition risks under future uncertainties, reduces fluctuations in cumulative abatement costs, and enhances the resilience of the energy system. These findings reveal the systemic impacts of CCS technological progress on China's low-carbon energy transition and provide a scientific basis for formulating differentiated CCS technology roadmaps and regionally coordinated emission reduction policies.

Paper ID: 272

Optimal value chains of bioenergy with carbon capture and storage (BECCS) systems

John Frederick Tapia[1,2], Amatha Viola Ferrer[2], Maria Victoria Migo-Sumagang[3], Stephen Doliente[4,5]

[1]Department of Chemical Engineering, De La Salle University Manila, 2401 Taft Avenue, Malate, Manila Philippines, 0922; [2]Center for Engineering and Sustainable Development Research, De La Salle University Manila, 2401 Taft Avenue, Malate, Manila Philippines, 0922; [3]Department of Chemical Engineering, University of the Philippines Los Baños, Laguna, Philippines.; [4]Bath Institute of Sustainability and Climate Change (ISCC), University of Bath, Claverton Down, Bath, BA2 7AY, United Kingdom; [5]Department of Chemical Engineering, University of Bath, Claverton Down, Bath, BA2 7AY, United Kingdom;
Email: john.frederick.tapia@dlsu.edu.ph

Abstract:

Carbon capture and storage (CCS) is one of the mitigations options that can reduce emissions from fossil-based power and manufacturing industries. It involves capturing CO2 from flue gas, transporting it through pipelines and injecting it into geological reservoir for permanent storage. The benefits from this technology can be intensified when coupled with bioenergy plants, resulting in near-zero to net-negative carbon emissions. Bioenergy with carbon capture and storage or BECCS is expected to provide larger contributions given the ubiquity of biomass feedstocks, such as agricultural waste. Yet biomass availability is highly uneven across regions and seasons, that can complicate feedstock–conversion matching and increase logistical burdens. Along with these challenges are land- and water-use pressures and sustainability concerns of biomass use that can constrain the large-scale deployment of BECCS. Hence, systematic planning and deployment of biomass conversion technologies to generate high-value energy products is needed to achieve the economic benefits of BECCS. The environmental benefits of BECCS can also be maximized through systematic planning. In this study, a mixed integer linear programming (MILP) model is developed for optimizing the economic and environmental benefits of value chain of BECCS. The model determines the scale of the biomass conversion technologies needed to meet the demands of one or more regions and the scale of CCS needed to achieve a target reduction. A case study is presented to illustrate the model. Results from the case study provide insights into balancing the trade-off between costs and GHG emissions reduction from the BECCS system.

Paper ID: 275

Modeling low-carbon transitions in residential construction waste systems: Long-term environmental implications

Wenbo Zhao, Jian Li Hao, Zhiqin Ni, Guobin Gong
Xi'an Jiaotong-Liverpool University, China, People's Republic of;
Email: Wenbo.Zhao22@student.xjtlu.edu.cn

Abstract:

Construction and demolition waste (CDW) is a major source of solid waste and global warming potential (GWP), making effective CDW management crucial for achieving the 2050 net-zero target. This study evaluates the long-term climate impacts of CDW disposal under multiple recycling strategies and addresses the lack of integrated frameworks for assessing life-cycle GWP and interactions among decarbonization strategies. Seven scenarios are developed, including five single-strategy scenarios, business-as-usual, behavioral-change, policy-intervention, market-driven, and technological-improvement, and two integrated-strategy scenarios representing medium-efficiency and best-practice pathways. Among the single strategies, technological improvement shows the strongest performance, achieving a 40% recycling rate and a 34.79% reduction in GWP by 2050, while behavioral, policy, and market-driven strategies yield lower recycling rates and emission reductions. Integrated strategies demonstrate significantly higher mitigation potential, with the medium-efficiency scenario increasing recycling to 59.4% and reducing GWP by 54.08%, and the best-practice scenario achieving near-complete recycling and a 93.75% reduction in GWP. The results indicate that advanced technologies and innovative construction practices are most effective when combined with behavioral, policy, and market interventions. This study provides quantitative insights to support policymakers in designing effective CDW management strategies to enhance recycling and reduce climate impacts, contributing to global net-zero goals by 2050.

Paper ID: 276

Managing organic input uptake in China's grain systems: stage-specific associations and regional heterogeneity

Yuan Lu, Yueshuai Li, Hao Wu, Weifeng Zhang, Yangyang Li
State Key Laboratory of Nutrient Use and Management, College of Resources and Environmental Sciences, National Academy of Agriculture Green Development, China Agricultural University, Beijing 100193, China.;
Email: yuanlu@cau.edu.cn

Abstract:

Sustainable nutrient management in grain systems depends in part on the wider use of locally available organic inputs, yet on-farm uptake remains low and uneven. This unevenness may reflect not only whether farmers start using organic inputs, but also how intensively adopters apply them under different regional conditions. Using 2,660 observations from the 2024 National Scientific Fertilization Survey across 12 Chinese provinces, this study examines organic input uptake in relation to diffusion-related conditions, fertilizer-related knowledge, capacity conditions, and attitudinal evaluation. A PLS path model estimates overall direct associations and indirect paths through attitudinal evaluation. Supplementary checks by uptake stage separate adoption incidence from conditional application intensity, and multi-group analysis compares path patterns across four sampled grain regions. Only 14.25% of sampled grain producers reported using organic inputs. In the main path model, all four conditions show positive paths to organic input uptake, with attitudinal evaluation showing the largest direct coefficient. The stage-specific checks suggest that fertilizer- related knowledge and capacity are more closely linked to adoption entry, whereas attitudinal evaluation and capacity are more closely linked to application intensity among adopters. Regional contrasts further indicate that capacity conditions are most prominent in the Eastern and Central samples, diffusion-related conditions in the Western sample, and attitudinal evaluation in the Northeastern sample. These findings suggest that support for organic substitution in grain systems should distinguish initial use from sustained application intensity and should be adapted to local management conditions.

Paper ID: 280

Large-scale application of photovoltaic direct-drive poe lighting in nearly zero carbon buildings

Xi Tian[1,2,3], Jiaojiao Huang[1], Fei Peng[1]
[1]School of Economics and Management, Nanchang University, Nanchang 330031, PR China; [2]Engineering Research Center of Watershed Carbon Neutralization of Ministry of Education, Nanchang University, Nanchang 330031, PR China; [3]Research Center for Central China Economic and Social Development, Nanchang University, Nanchang 330031, PR China;
Email: jiaojiaohuang99@163.com

Abstract:

Distributed photovoltaics (DPVs) can decarbonize building lighting, but the associated power delivery still relies on multi-stage power-electronic conversions and lack load-coupled intelligent control, limiting achievable efficiency and emission reductions. This study evaluates the life-cycle economic and carbon performance of a DPV direct-driven Power-over-Ethernet lighting system (DPV-DD-PoE) and compares it with three reference configurations over a 30-year period: traditional grid-supplied lighting (TG), grid-connected DPV lighting without storage (DPV-GC), and off-grid direct-driven photovoltaic–battery storage lighting without an inverter (DPV-DD-BS). The assessment uses daily operational data from two demonstration buildings and applies sensitivity analyses to test key techno-economic and environmental uncertainties. Moreover, using China as a case study, the regional deployment potential was evaluated by integrating building DPV potential, electricity prices, population density, and solar irradiance. Results show that: (1) DPV-DD-PoE reduces cumulative life-cycle carbon emission to 0.32 kt CO2-eq (an 87.1% reduction) under the TG baseline; (2) DPV-DD-PoE delivers the lowest levelized cost of energy ($0.036/kWh) and the highest net present value (41% higher than DPV-GC). (3) Nationwide deployment DPV-DD-PoE could generate $128.8 billion yr-1 in economic benefits and reduce emissions by 586 Mt CO2-eq yr-1. The greatest near-term value is observed in monsoon regions with substantial industrial and public-building lighting demand. Direct DC delivery reduces conversion losses and replacement burdens, whereas PoE-based sensing reshapes terminal demand; together, these mechanisms improve PV-load matching and carbon–economic performance. The proposed framework supports scalable lighting-system pathways that can contribute to building-level net-zero targets.

Paper ID: 283

The potential of drilling wastes utilization through thermochemical process and kinetics study: mud, cuttings, and spent lubricant oil from oil and gas industry

Patranit Worakitchareonpol[1], Jurarat Nisamaneenate[1], Kritchart Wongwailikhit[2], Siraphop Tocharoen[1], Duangduen Atong[3], Viboon Sricharoenchaikul[1,4]

[1]Department of Environmental and Sustainable Engineering, Faculty of Engineering, Chulalongkorn University, Thailand; [2]Department of Chemical Engineering, Faculty of Engineering, Chulalongkorn University, Thailand; [3]National Metal and Materials Technology Center, Thailand Science Park, Thailand; [4]Energy Research Institute, Chulalongkorn University, Thailand;

Email: patranit.envg@gmail.com

Abstract:

The sustainable management of petroleum drilling wastes remains a critical environmental challenge in the oil and gas sector, as conventional disposal practices fail to exploit their latent energy potential. This study investigates the thermochemical valorization of three co-generated drilling waste streams: drilling mud (DM), drill cuttings (DC), and spent lubricant oil (SLO) through thermal decomposition kinetics, thermodynamic evaluation, and pyrolytic oil recovery analysis. Kinetic modelling identified distinct decomposition mechanisms governing mass loss behavior. SLO followed a first order reaction model (F1) with an activation energy of ~100 kJ/mol, establishing its suitability for energy recovery via gasification. Conversely, DM decomposition was primarily diffusion controlled (D1) due to surface layer formation, while DC exhibited high order reaction models (F3 and F5), reflecting complex hydrocarbon desorption from porous rock matrices. Thermodynamic assessments confirmed that pyrolysis of all samples was endothermic and nonspontaneous. The initial decomposition stages of DM and DC required relatively low activation energies (55 - 65 kJ/mol), presenting energetically viable conversion pathways. Thermal treatment further facilitated the extraction of high-quality drilling waste oil with enriched hydrocarbon content of 88 - 93%, establishing it as a viable syngas production feedstock. Steam reforming of the recovered oils achieved maximum hydrogen and carbon conversions of 82.41% and 58.43%, respectively, with a syngas lower heating value of 6.99 MJ/m3. In conclusion, these findings confirm that drilling wastes carry recoverable fuel value accessible through established thermochemical routes and provide the kinetic and thermodynamic parameters necessary for reactor design and process scale up toward their deployment as secondary fuel sources.

Paper ID: 284

An innovative Back-to-Furnace treatment strategy for MSWI fly ash: dynamic modeling of pollutant fate and process performance

Jianing Liang[1], Dongbei Yue[1,2], Hongxin Li[1], Songrun Liang[1], Danlei Cai[1]
[1]School of Environment, Tsinghua University, Beijing 100084, China; [2]State Key Laboratory of Iron and Steel Industry Environmental Protection, School of Environment;
Email: liangjianingbest@163.com

Abstract:

Managing municipal solid waste incineration (MSWI) fly ash is a global challenge due to high concentrations of chloride salts, dioxins, and heavy metals. These substances are harmful to the environment and lead to high disposal costs. Back-to-Furnace (BtF) recirculation of MSWI fly ash has emerged as a promising solution for volume and toxicity reduction and resource recovery. However, the complex interplay between process parameters and the dynamic behavior of pollutants (e.g., heavy metals and chlorine) within the loop remains poorly understood, posing challenges for optimization and risk control.

This study develops a dynamic system model to simulate the full-scale BtF process, aiming to elucidate the fate and accumulation patterns of representative substances with different volatilities—namely mercury (Hg, volatile), cadmium (Cd, semi-volatile), chromium (Cr, hardly volatile), and chloride salts - and to evaluate key operational interventions. The model is structured as a multi-node material flow model encompassing all major units, including fly ash generation, in-furnace conditioning (e.g., sintering, reagent addition, and flue gas treatment), baghouse collection, and external conditioning (e.g., washing and reagent addition) prior to recirculation. The model incorporates substance-specific partition coefficients and reaction kinetics derived from literature and preliminary experiments. Both forward simulations (predicting system response to disturbances) and backward calculations (deriving unit performance targets from final emission goals) were performed.

The model serves to predict steady-state concentrations and estimate the time to equilibrium. By adjusting the recycling ratio and process parameters for incineration or washing, users can optimize final concentrations. Furthermore, backward analysis demonstrates how tightening the final emission targets for pollutants would necessitate corresponding increases in the removal efficiencies of upstream control units. This work provides a quantitative framework for understanding and optimizing MSWI fly ash BtF recirculation, providing guidance for technology development and operational decisions, ultimately contributing to safer resource recovery from incineration residues.

Paper ID: 286

Beyond economic incentives: how loss aversion shapes local governments' response to green finance in urban blue-green infrastructure

Lanya Zhang, Linyu Xu

Beijing Normal University, China, People's Republic of;

Email: zlyjr98@163.com

Abstract:

Green finance is a pivotal instrument for promoting urban sustainability. However, its ultimate impact depends on the behavioral responses of local governments. We develop a dual-driver theoretical framework that integrates a neoclassical efficiency trade-off model with insights from prospect theory. The analysis reveals that the policy triggers two opposing forces. First, it induces an efficiency-substitution effect, where improved financing efficiency allows governments to meet environmental goals with less land. Second, it activates a loss-aversion effect. Our empirical tests, including heterogeneity analyses based on environmental performance thresholds, corroborate that this behavioral channel is a primary driver of the observed suppression effect. This study offers theoretical foundations and empirical insights for green finance development and the trend of local government behaviors.

Paper ID: 287

Saline-alkali land improvement measures effectively increase crop yields

Zhongxiao Sun, Yue Li, Jiayi Xu, Qian Zhang
China Agricultural University, China, People's Republic of;
Email: z.sun@cau.edu.cn

Abstract:

Global food security faces a dual challenge--the rising demand for biological resources and the degradation of physical cropland.Saline-alkaline land plays a critical role in food security and is essential for sustainable agriculture. However, there is no a comprehensive evaluation of reclamation strategies across varying environmental contexts. Here, we analyzed the studies associated with saline-alkaline land research since 2000. We assessed the impact on soil salinity and crop yield of four intervention modes, including hydraulic, physical, chemical, and biological modes. We found that biological measures are superior overall. Biological interventions achieved the highest salinity reduction (59%) and yield increase (267%). Hydraulic measures reduced salinity by 36% and boosted yields by 132%. Physical and chemical methods proved less effective. In addition, we distinguished regional optimalities. Hydraulic measures maximized yields in the Eastern Coastal region (174% increase). Physical measures proved most effective in the Northeast Plain (106% increase). In the arid Northwest Inland, biological strategies—specifically salt-tolerant cropping—delivered a massive 311% yield surge. These findings indicate that sustainable resource management requires site-specific strategies. We hope our study could provide a scientific basis for policymakers to optimize land resource allocation and ensure long-term sustainability of saline-alkaline land.

Paper ID: 288

Dual-sided superhydrophobic paper prepared via gas-phase silylation for breathable, recyclable mono-substrate packaging

Patcharawarin Sathapornwajana[1], Kuntinee Suvarnakich[1,2], Kamonwan Pacaphol[1,2,3]
[1]Pulp, Paper and Packaging Technology Program, Faculty of Science, Chulalongkorn University, Bangkok, 10330, Thailand.; [2]Department of Imaging and Printing Technology, Faculty of Science, Chulalongkorn University, Bangkok, 10330, Thailand.; [3]Center of Excellence in Responsive Wearable Materials, Chulalongkorn University, Bangkok, 10330, Thailand.;
Email: patcharawarin.sa@gmail.com

Abstract:

As mono-material substrates are increasingly designed for better recyclability and as concerns grow over the environmental impact of plastic waste, paper has emerged as an attractive mono-material packaging candidate due to its biodegradability and ready recyclability; however, its poor water resistance still limits practical applications. In this study, breathable and water-resistant paper was developed via gas-phase silylation using chemical vapor deposition (CVD). A silane with a long hydrocarbon chain (HDTMS) was introduced in the vapor phase together with titanium(IV) isopropoxide (TTIP) as a catalytic primer. In contrast to conventional liquid-based paper coating, which typically forms a layer mainly on the coated face and relies on coating baths that generate wastewater requiring treatment, the vapor-phase route enables reagent diffusion through the porous fiber network, delivering water resistance on both sides of the paper sheet without a coating bath. This process used very low chemical input (approximately 0.2–2 mL/m²), far below conventional paper coating operations, thereby reducing material consumption, coating-bath residues, and effluent management burdens. The optimum formulation was achieved at 0.8 mL/m² of HDTMS and 3% v/v of TTIP at 150 °C and 30 min of vapor deposition, in which the paper exhibited superhydrophobicity, with the water contact angle increasing from 0° to 153°. Water absorption was significantly suppressed, with Cobb values reduced from 440 to 19 g/m². Importantly, air permeability was preserved, with oxygen transmission and water vapor transmission rates exceeding 2,000 cm³/m²·day and 60 g/m²·day, respectively. These properties enable applications such as wound care materials and fresh-produce packaging that require both water resistance and good air permeability. Designed as a paper-based mono-substrate without plastic lamination, the material remains compatible with conventional paper recycling, supporting circular economy flows while reducing reliance on non-biodegradable plastic films.

Paper ID: 290

Net carbon dioxide removal potential of cement kiln dust enhanced weathering in Malaysia's oil palm plantations

Kathleen Aviso[1], Dominic Foo[2], Ivan Gue[1], Maria Victoria Migo-Sumagang[3], Denny Ng[4], Raymond Tan[1], Yin Ling Tan[5]

[1]De La Salle University, Philippines; [2]University of Nottingham, Malaysia; [3]University of the Philippines Los Banos, Philippines; [4]Sunway University, Malaysia; [5]Curtin University Malaysia, Malaysia;
Email: kathleen.aviso@dlsu.edu.ph

Abstract:

Enhanced weathering of alkaline minerals in palm plantations is a scalable decarbonization strategy for palm oil-producing countries. However, recent findings show that using powdered basalt for this purpose will result in emissions penalties from mining, rock crushing, and logistics that will offset about half of the direct carbon dioxide removal (CDR) benefits. Cement kiln dust, a waste material from Portland cement production, can be used to replace basalt without the same emissions penalties while also putting an industrial waste material to beneficial use. In this work, environmentally extended input-output analysis is used to estimate the net CDR from enhanced weathering of cement kiln dust in Malaysia. Cement kiln dust is found to be superior to basalt in terms of CDR efficiency, but its scalability is limited by supply. We discuss the potential of enhanced weathering as a key strategy to decarbonize the global palm oil industry.

Paper ID: 293

Recycling lock-in in electronic waste management systems

Mika Portugaise
Department of Engineering Science, University of Oxford, United Kingdom;
Email: mika.portugaise@eng.ox.ac.uk

Abstract:

Electronics' lifecycles are a critical sector for Circular Economy intervention due to the embedded reuse or economic value of metals, rare earth elements, and other recyclable resources, as well as the potential harm inflicted upon environmental and human health if improperly managed. Yet the electronics – electronic waste (e-waste) lifecycle is increasingly structured around recycling as the dominant treatment pathway, impeding higher-value circular strategies such as reduction, reuse, repair, and remanufacturing. Through an embedded, single-case study of the Japanese consumer e-waste system, this paper applies lock-in theory (path-dependent entrenchment of dominant practices) to define recycling lock-in of e-waste - and examines its development from initial contributing factors to embeddedness over time. Through the study of archival data, this paper examines how recycling lock-in creates barriers to expansion of the e-waste management system, and how higher-R strategies may be employed to combat these barriers and create more comprehensive circular electronics' lifecycles. This study further employs an inductive Gioia-based approach by analyzing semi-structured research interviews to explore stakeholders' experiences of the case system's origins and development towards recycling lock-in over time, determine what higher-R strategies exist within the system, and how these may contribute to breaking lock-in.

By providing a novel definition of recycling lock-in of e-waste and an analysis of the complex factors contributing to its formation and entrenchment, this study presents policymakers and researchers with a basis for comparing states of recycling lock-in in mature e-waste management systems, as well as pitfalls to avoid in nascent systems. Furthermore, exploration of approaches to breaking recycling lock-in of electronic waste contributes more broadly to Circular Economy literature in other sectors experiencing lock-in challenges.

Paper ID: 296

Beneficial reuse of waterworks sludge in different scenarios in environmental and civil engineering

Yaqian Zhao
Xi'an University of Technology, China, People's Republic of;
Email: yzhao@xaut.edu.cn

Abstract:

Waterworks sludge refers to the inevitable by-product generated during the drinking water purification process, where Al or/and Fe salts are used as a coagulant in the water industry. It has long been treated as “waste”, while landfill is its major final disposal destination. In fact, waterworks sludge is an underutilized material with huge potential for beneficial reuse as a raw material in various wastewater treatment processes and municipal and civil engineering. In the last two decades, intensive studies have been conducted worldwide to explore the “science” and practical application of the waterworks sludge.

This presentation focuses on the recent developments in the use of waterworks sludge that show its strong potential for reuse of different scenarios in wastewater treatment processes, environmental and even civil engineering. In particular, the presentation covers the key “science” of the nature and mechanisms of the waterworks sludge, revealing why it has the potential to be a value-added material. In addition, the future focus of research towards the widespread application of waterworks sludge as a raw material/product in commercial markets is suggested, which expands the scope for research and development of the waterworks sludge.

Paper ID: 302

A circular economy route to hydrogen via microwave reforming of spent transformer oil over sewage sludge-derived Ni-Co catalysts

Siraphop Tocharoen[1], Jurarat Nisamaneenate[1], Patranit Worakitchareonpol[1], Duangduen Atong[2], Viboon Sricharoenchaikul[1,3]

[1]Department of Environmental and Sustainable Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok 10330, Thailand; [2]National Metal and Materials Technology Center, Thailand Science Park, Pathumthani 12120, Thailand; [3]Energy Research Institute, Chulalongkorn University, Bangkok 10330, Thailand;

Email: nut117.siraphop@gmail.com

Abstract:

This study investigated microwave-induced catalytic steam reforming of spent transformer oil (STO), a hazardous waste, over non-noble metal catalysts supported on sewage sludge-derived activated carbon (SSAC) for sustainable hydrogen-rich syngas production. Sewage sludge from a beverage industry wastewater treatment facility was pyrolyzed at 500 °C and chemically activated with KOH to produce SSAC, which was subsequently loaded with Ni and Co via wet impregnation. The feedstock was characterized by proximate analysis, ultimate analysis, TGA-Micro GC/MS, and Py-GC/MS, while the catalysts were examined using XRD, BET, SEM-EDS, XPS, and FTIR. The SSAC exhibited a predominantly amorphous carbon structure with a high BET surface area of 1001.2 $m^2 g^{-1}$ and a mesoporous network (average pore diameter of 3.49 nm), which decreased after metal loading but retained mesoporous characteristics favorable for heavy hydrocarbon diffusion. The effects of microwave power (600–840 W) and catalyst composition on hydrogen and carbon conversions were evaluated. Both conversions increased with microwave power, reaching a maximum at 840 W. Among the catalysts tested, the bimetallic 5%Ni5%Co/SSAC exhibited the highest performance, achieving hydrogen and carbon conversions of 81.17% and 68.47%, respectively, attributed to the synergistic interaction between Ni and Co species. These results demonstrate that SSAC-supported Ni–Co catalysts offer a promising route for upcycling both sewage sludge and STO into valuable hydrogen-rich syngas through microwave-induced steam reforming.

Paper ID: 306

Environmental sustainability assessment of plastic-modified tire-derived aggregates in subsurface asphalt pavement mixtures

Neetu Gopakumar, Namitha Sudan, Krishna Prapoorna Biligiri
Indian Institute of Technology Tirupati,
Email: India; bkp@iittp.ac.in

Abstract:

The growing accumulation of end-of-life tires and post-consumer plastics has intensified the need for resource-efficient and sustainable pavement solutions aligned with circular economy principles. Modified tire-derived aggregates (MTDA) developed using high-density polyethylene (HDPE), polyethylene terephthalate (PET), and polypropylene (PP) wastes offer promising alternatives for asphalt pavement subsurface applications. However, their environmental implications at both material and mixture scales remain largely unexplored. Therefore, the major objective of this study was to quantify the cradle-to-gate environmental impacts of MTDA products from HDPE, PET, and PP as well as MTDA-incorporated asphalt mixtures to assess their environmental viability as substitutes for conventional mineral aggregates in rubberized subsurface layers of the pavement systems. The scope of the effort was twofold: (i) estimation of the potential environmental impacts associated with MTDA production using HDPE, PET, and PP, and comparing MTDA systems with conventional aggregates, and (ii) quantification of the environmental impacts associated with asphalt mixture production using MTDA and conventional aggregates across selected midpoint impact categories. The study adopted a two-scale analysis using a declared unit of 1 metric ton of MTDA, and the functional unit of asphalt mixture was defined based on a critical performance parameter of subsurface systems, namely, triaxial resilient modulus (MR) to ensure performance-equivalent comparison amongst MTDA-modified and conventional asphalt mixtures mainly to enable a function-based evaluation of sustainability indicators. The lifecycle impact assessment was conducted using the ReCiPe 2016 impact assessment method in openLCA® software. Results indicated that amongst the MTDA variants, MTDA-PET and MTDA-HDPE exhibited the most favorable overall environmental profiles, albeit a marginal increase was observed in fossil fuel potential, reflecting additional processing requirements associated with plastic modification. Overall, the research demonstrated the potential of MTDA-based asphalt mixtures to advance resource-efficient pavement infrastructure through informed lifecycle-based decision-making.

Paper ID: 307

Resource sustainability assessment of waste-derived warm-mix additives for asphalt-rubber pavements

Sri Gangadhar Mattaparthi, Namitha Sudan, Krishna Prapoorna Biligiri
Indian Institute of Technology Tirupati,
Email: India; bkp@iittp.ac.in

Abstract:

Asphalt-rubber (AR) pavements have shown improved structural and functional performance over conventional hot-mix asphalt (HMA) pavements in all-road and all-weather conditions. However, the major challenge associated with the AR binders is high production temperatures at the asphalt plant ascribed to higher viscosities at higher temperatures due to the inclusion of crumb rubber particles. Warm-mix asphalt (WMA) technology has emerged as a promising alternative to traditional HMA production, thus manufacturing the mixtures at relatively lower temperatures without compromising material performance. Nevertheless, issues such as patented processes and the nonavailability of products in the commercial market hinder advancement in research and refinement of the available WMA additives. Consequently, there exists a global need for cost-effective and material-efficient WMA additives specifically tailored for AR mixtures, which fundamentally necessitates a shift in the material design philosophy of WMA additives from proprietary chemistry to resource-derived formulation. Therefore, the primary objective of this study was to quantify and compare the environmental impacts associated with the laboratory-synthesized aluminosilicate-based WMA additives derived from natural clay and industrial fly ash, chiefly to evaluate the sustainability metrics of incorporating the selected additive into HMA and AR systems. A two-level lifecycle assessment (LCA) was carried out using openLCA® software with the ReCiPe 2016 midpoint (H) impact assessment method. Results indicated that fly ash-derived additive reduced global warming potential by approximately 82%, fossil resource scarcity by 78%, terrestrial ecotoxicity by 76%, and mineral resource scarcity by 67% relative to the clay-derived additive. Overall, the findings demonstrated that the sustainability advantage of resource-derived aluminosilicate additives originated primarily at the material-production stage, while their incorporation into HMA and AR mixtures did not introduce disproportionate environmental burdens, thereby validating the transition from proprietary chemistry to waste-based formulations as a technically viable and environmentally responsible pathway for circular waste-to-wealth pavement material formulations.

Paper ID: 308

Development of a real-time structural performance-based framework for use-phase environmental assessment of asphalt pavement system

Namitha Sudan, Krishna Prapoorna Biligiri
Indian Institute of Technology Tirupati, India;
Email: bkp@iittp.ac.in

Abstract:

Traditionally, the pavement lifecycle assessment has relied on arbitrary surface condition thresholds and service life assumptions without real-time monitoring of pavement systems in quantifying the environmental sustainability metrics. Despite the effectiveness of surface condition-based indicators in approximating the functional performance of existing pavements, it limits the understanding of real-time pavement-vehicle interaction and its influence on excess fuel consumption of vehicles. In particular, the energy loss in vehicles due to traffic-induced viscoelastic deformation in pavement, which is estimated as structural rolling resistance must be incorporated along with real-time roughness in determining the excess vehicle energy demand. The objective of this research study was to develop an integrated framework that combines environmental impact assessment and pavement structural performance based on real-time data collected from a newly constructed pavement system in service. The scope of the study encompassed: (i) evaluation of the strain accumulation over time within the pavement structure under traffic loading, (ii) estimation of structural rolling resistance and excess fuel consumption to estimate the associated emissions during the use-phase, and (iii) quantification of total environmental impact indicators associated with the existing pavement structure using ReCiPe 2016 lifecycle assessment methodology. Thus, this study examined the dynamic interaction between pavement deterioration and the environmental performance by coupling the real-time structural performance of the existing pavement system with the environmental impacts during the use phase. The results indicated that structural rolling resistance increased progressively with pavement deterioration over time, leading to a measurable increase in vehicle fuel consumption during the use-phase. Further, the study also evaluated the use-phase emission trajectory corresponding to the evolution of structural rolling resistance over time. Overall, this study bridges the gap between environmental assessment and structural performance evaluation, supporting decision-making for sustainable pavement design and asset management.

Paper ID: 309

Attributional lifecycle assessment of asphalt pavements reinforced with composite glass fiber grids as crack-relief layers

Hrushikesh Pandurangi[1], Namitha Sudan[1], Neetu Gopakumar[1], Abhijith B S[2], Krishna Prapoorna Biligiri[1]
[1]Indian Institute of Technology Tirupati, India; [2]Saint-Gobain ADFORS India;
Email: bkp@iittp.ac.in

Abstract:

Composite glass fiber grid (CG) interlayer systems are increasingly adopted as a crack-relief layer in flexible pavements to enhance resistance against crack propagation and improve structural integrity. Despite the extended service life and enhanced structural performance of CG incorporated systems, the associated environmental implications have not been adequately investigated. Thus, the objective of this study was to compare the effectiveness of a CG-incorporated pavement system with the conventional asphalt pavement with an aggregate interlayer as a crack relief layer. The scope of the study included: (i) design and analysis of pavement systems, (ii) cradle-to-laid attributional lifecycle assessment of the pavement systems using OpenLCA© software, and (iii) sensitivity analysis of environmental impacts considering alternative maintenance activities to assess the benefits of service life extension. The pavement system reinforced with a CG interlayer was modeled using Abaqus® software to understand the structural response of the system. The primary foreground data, including the construction and installation details were collected directly from the industry stakeholders. The results indicated that although the declared unit of the CG-installed pavement system had a marginal increase in the environmental impacts during the construction stage, augmented durability reduced the overall environmental burden. However, the analysis using the performance-adjusted functional unit indicated that the CG-installed pavement system exhibited a lower global warming potential overall due to reduced raw material consumption and fewer maintenance interventions over the analysis period. Additionally, it was found that the CG interlayer accounted for a relatively lower impact when compared to the other raw materials such as asphalt binder and natural aggregates in the case of the performance-adjusted functional unit. Overall, the findings highlighted the importance of incorporating a CG interlayer into the pavement system, which improved its long-term environmental performance while also extending its service life.

Paper ID: 317

Transforming coconut husk waste into sustainable biochar adsorbents for CO_2 capture

Ratchanan Chamnanmor[1], Leangse Meng[1], Siraphop Tocharoen[1], Jurarat Nisamaneenate[1], Pisut Painmanakul[1], Thaksina Poyai[2]

[1]Department of Environmental and Sustainable Engineering, Faculty of Engineering, Chulalongkorn University; [2]Department of Environmental Engineering, Faculty of Engineering, Kasetsart University; Email: ratchanan.ch@gmail.com

Abstract:

This study investigates the potential of biochar derived from coconut husk as a sustainable adsorbent for CO2 capture. The biochar yield, physicochemical properties, and CO2 adsorption performance were evaluated at 500 °C and 600 °C, selected based on thermogravimetric analysis. Pyrolysis was conducted under a nitrogen atmosphere with a heating rate of 5 °C min-1, a residence time of 1 h, and a nitrogen flow rate of 100 mL min^{-1}. The resulting biochar was characterized using ultimate analysis, Brunauer-Emmett-Teller surface area analysis, Fourier-transform infrared spectroscopy, X-ray diffraction, and scanning electron microscopy. CO2 adsorption performance was assessed in a quartz-tube fixed-bed reactor packed with 1 g of adsorbent at an initial CO2 concentration of 500 ppm under ambient conditions (25 °C and 1 bar). Results indicate that pyrolysis temperature significantly influences the physicochemical characteristics of coconut husk biochar. Carbon content increased from 38.50% in raw coconut husk to 54.53% at 500 °C and slightly decreased to 50.15% at 600 °C, while oxygen content declined with increasing temperature, suggesting enhanced deoxygenation. Biochar yield decreased from 53.55% (at 500 °C) to 44.84% (at 600 °C) due to devolatilization during pyrolysis. Structural analyses revealed the conversion of lignocellulosic biomass into aromatic carbon structures, and FTIR spectra confirmed the presence of hydroxyl, phenolic, ether, and aromatic functional groups that may serve as active sites for CO2 adsorption. The highest CO2 adsorption capacity (0.079 mmol g-1) was achieved at a pyrolysis temperature of 600 °C. The Avrami model adequately described the adsorption kinetics (R2 = 0.74-0.94), while the Toth model showed an excellent fit for equilibrium data (R2 = 0.96-0.99). These findings highlight the potential of coconut husk biochar as a low-cost and sustainable material for CO2 capture, contributing to agricultural waste valorization and resource sustainability.

Paper ID: 319

What consumers actually discard: material evidence of resource recovery misalignment in post-consumer textile systems

Magnum Man-lok Lam, Zeyu Liu, Shiqi Mai, Icey Li, Christina W.Y. Wong

The Hong Kong Polytechnic University, Hong Kong S.A.R. (China);

Email: magnumml.lam@polyu.edu.hk

Abstract:

Post-consumer garments constitute a major stream of misplaced textile resources, yet the effectiveness of recycling systems depends not only on participation rates but on the material suitability of items entering recovery channels. Existing research on sustainable disposal has largely relied on survey-based and intention-focused accounts of consumer behavior, offering limited evidence on the material characteristics of garments that actually enter different circular recovery pathways. This study addresses this gap through a systematic material composition analysis of 552 post-consumer garments (252 kg) collected from organized garment collection and recovery initiatives in Hong Kong. Garments were classified by functional category, quality condition, seasonality, gender orientation, and fiber composition to assess reuse and recycling potential.

The findings reveal a pronounced disconnect between sustainability participation and material recovery feasibility. A substantial proportion of discarded garments (43.4%) were fully functional, indicating premature diversion from continued use. At the same time, high proportions of synthetic (26.7%) and unknown (36.1%) fiber compositions constrain fiber-to-fiber recycling potential. These patterns demonstrate that consumers frequently channel wearable and materially complex garments into recycling streams without evaluating their suitability for reuse or high-value recovery. The convergence of premature disposal and material incompatibility suggests limited consumer task knowledge regarding garment quality, fiber composition, and appropriate end-of-life pathways. Participation in garment collection and recovery initiatives thus functions as a norm-driven routine rather than a materially informed practice, weakening circular resource efficiency. The results suggest that sustainability strategies must move beyond raising general environmental awareness toward enhancing material and quality literacy through clearer labelling, disposal guidance, and targeted communication. Aligning sustainability messaging with product design, fiber choices, and realistic recovery options can help ensure that consumer participation translates into materially effective outcomes, thereby strengthening the credibility and impact of sustainability-oriented marketing and resource management efforts.

Paper ID: 321

Navigating the last mile of green energy: multi-entity synergy and spatiotemporal cost-benefit evolution of heterogeneous PV recycling modes in China

Li Jing, Song Shen
Taiyuan University of Technology, People's Republic of China;
Email: Jinglibuaa@yeah.net

Abstract:

China is currently facing a large-scale retirement of decommissioned photovoltaic (PV) modules and urgently requires the establishment of a comprehensive mode for the recycling of PV waste components. There are few systematic analyses of multi-entity responsibility recycling modes for end-of-life PV modules. In this study, we constructed three recycling modes involving multi-entity responsibilities with a comprehensive cost-benefit model incorporating 11 elements to provide a comprehensive evaluation of the cost-benefit differences among these modes under various changing scenarios. The results showed that recycling modes involving retailers and third parties recycling showed optimal economic performance, with lower cost (93.07 million CNY) than the other two modes (101.16 and 113.38 million CNY, respectively). Structural analysis of the total cost indicated that the collection, storage, transportation, and processing stages were critical for cost control in all three modes. Scenario analysis showed that recovery scale expansion can enhance the net benefit, while the net benefit would decline if the network optimization exceeded 20% or the maximum storage duration was extended. In terms of comprehensive optimization, the greatest net benefit could be achieved in all modes by simultaneous recovery scale expansion, network optimization, and restricting the storage duration to 30 days. These findings verify the economic feasibility of multi-entity responsibility modes for PV recycling, providing an important theoretical reference and practical directions for the construction of an efficient and low-cost system for the recycling of retired PV modules.

Paper ID: 322

Assessing agricultural water resource resilience under climate change using life cycle assessment: a case study of the Shihmen Reservoir in Taiwan

Cian-Wei Chiang[1], Yen-Tzu Fan[1,2], Pei-Te Chiueh[1]
[1]National Taiwan University, Taiwan; [2]The University of Melbourne, Australia;
Email: ptchueh@ntu.edu.tw

Abstract:

Agricultural water shortage and deterioration have become critical challenges under climate change, threatening both food supply and safety. To strengthen water management the face of climate impacts, this study evaluates the resilience of agricultural water supply and demand under climate change within the Shihmen Reservoir service area, Taiwan, and explores implications for nature-based solutions. Given that agriculture accounts for a major portion of Taiwan's water consumption and is therefore highly exposed to water scarcity, we developed a regionalized life cycle assessment (LCA) framework integrating water scarcity risk indicators with sector-specific fate, exposure, and effect factors for the agricultural, domestic, and industrial sectors. Administrative districts within the reservoir's supply area served as spatial units for impact assessment.

Future water availability was estimated based on changes in Q85 flow, while future water demand and characterization factors were projected using population and land-use data under the SSP2-4.5 and SSP5-8.5 scenarios for the near-term and mid-term periods. The results identify Dayuan, Guanyin, Xinwu, and Yangmei as potential agricultural high-risk hotspots, consistently showing relatively high agricultural endpoint characterization factors. Seasonal contrast between wet and dry periods becomes more pronounced in the mid-term future, suggesting increasing imbalances in water allocation due to climate change. The results also reveal strong spatial heterogeneity. Climate impacts decrease in some districts due to greater wet-season water availability and population decline, while climate impacts increase in others where dry-season water availability diminishes faster than water demand. These findings provide a spatially explicit basis for identifying adaptation priorities and supporting future water resource management and nature-based solutions.

Paper ID: 323

From persistence to adaptation: evaluating ecological resilience and zoning strategies in a high-density coastal megaregion

Xing Zhang, Linyu Xu, Jiakang Hao
Beijing Normal University, China, People's Republic of;
Email: 448345072@qq.com

Abstract:

High-density coastal megaregions face escalating anthropogenic and climatic pressures, yet resilience assessments often lack integrated, process-oriented frameworks. We develop a multidimensional

Persistence-Recovery-Adaptability (PRA) framework and a Resilience Strategy Evolution Ellipsoid to assess ecological resilience dynamics in the Guangdong-Hong Kong-Macao Greater Bay Area (1990~2020). The region experienced an overall resilience decline until 2010, followed by divergent city-level trajectories: Structural Decay, Resilience Trap, and Disconnected Pockets. PRA decomposition clarifies the mechanisms behind these pathways. Scenario simulations (PLUS model) show that an innovation-oriented marine economy shifts Zhuhai from a defensive posture to a more adaptive configuration, moderately improving resilience over baseline. However, a declining trend toward 2050 underscores systemic constraints and a critical trade-off: enhanced adaptability may erode recovery capacity. This process-oriented, multi-scale framework advances resilience diagnosis beyond static snapshots, supporting targeted ecological zoning and adaptive planning in high-density coastal megaregions.

Paper ID: 326

Toward a governance framework for sustainable packaging systems in Japan: institutions, coordination, and participation in the circular economy transition

Akemi Ori
Sophia University, Graduate School of Global Environmental Studies, Tokyo, Japan;
Email: a-ori-c4t@sophia.ac.jp

Abstract:

The global shift toward a circular economy (CE), driven by the EU Packaging and Packaging Waste Regulation (PPWR), the forthcoming UN Plastics Treaty, and 2050 net-zero commitments, requires packaging to be reconsidered not merely as a material artifact but as a socio-technical system shaped by institutions, industrial coordination, and public participation. Japan has developed a highly optimized, material-specific recycling regime over the past three decades. However, this institutional arrangement now constrains the cross-material coordination of distribution, consumption, and recovery required for CE.

This study addresses three research questions: (RQ1) what institutional and technological bottlenecks does Japan's material-by-material optimization generate in the CE transition? (RQ2) how can the principle of "right material, right place" be translated into an analytical framework and decision-oriented criteria informed by lifecycle considerations, distribution requirements, and institutional arrangements? and (RQ3) how does a Japanese model of co-creation-driven innovation complement the EU's regulation-led approach?

The study develops a three-layer analytical framework combining (i) a lifecycle-based perspective on cross-material packaging choices, (ii) comparative institutional analysis of Japan and the EU, and (iii) stakeholder-oriented examination of distribution systems, business-model innovation, and consumer roles, based on ongoing empirical observations and stakeholder engagement. It also proposes a three-type breakthrough matrix to organize sectoral innovations into technological, business-model, and collaborative dimensions. Empirically, the study draws on the Sophia University Sustainable Packaging Study Group, a multi-stakeholder platform involving approximately 25 firms, regulators, and researchers.

Preliminary findings suggest that fragmented institutional arrangements undermine system-wide coordination; pre-competitive inter-firm collaboration and business-model innovation are crucial for overcoming firm-level constraints; and consumers need to be repositioned from passive sorters to active participants in circular systems. The study proposes a governance framework for sustainable packaging systems in Japan and offers a theoretically grounded perspective on CE transition with implications beyond Europe.

Paper ID: 328

Strategies for enhancing social benefits in agricultural waste management: a game theory approach to government subsidy policies

Li Gong Li
Taiyuan University of Technology, China, People's Republic of;
Email: liligong@tyut.edu.cn

Abstract:

This paper explores a resource utilization governance model that uses concentrated industrial production to transform agricultural waste into energy and fertilizer, aiming to reduce surface pollution and support the agricultural Circular Economy(CE). However, challenges such as raw material collection difficulties, low stakeholder participation, and limited social benefits persist. To address these issues, we develop a decision-making game model for an agricultural waste recovery and organic fertilizer production supply chain involving farmers, manufacturing enterprises, and the government. We analyze three subsidy strategies—no subsidy, subsidies to farmers, and subsidies to enterprises—while considering regional factors such as waste density and road complexity. Our results show that subsidies to both farmers and enterprises increase waste recycling and social welfare. Specifically, in regions with high waste density and complex roads, subsidies should target manufacturing enterprises, while in areas with flat terrain and high waste density, subsidies should favor farmers. In regions with low waste density and complex terrain, farmers should be prioritized. These findings propose solutions and policy recommendations for enhancing government involvement in agricultural waste management and guiding corporate investment decisions.

Paper ID: 329

Multi-task learning for multivariate load forecasting in integrated energy systems considering deep correlation features

Wenting Zhao
Taiyuan University of Technology, China, People's Republic of;
Email: zhaowenting@tyut.edu.cn

Abstract:

Multivariate load forecasting is crucial for the planning, scheduling, and enhancement of operational stability, economic efficiency, and reliability in integrated energy systems (IES). Traditional deep learning methods often struggle to fully mine the deep correlation features of IES multivariate loads and handle the strong volatility and nonlinear coupling in IES load data, which leads to a decline in forecasting accuracy and generalization capability. To overcome these challenges, this paper proposes a multi-task learning (MTL) based multivariate load forecasting method for IES considering deep correlation features. First, data preprocessing and Uniform Information Coefficient (UIC) feature selection are performed. The historical load sequences are then denoised using Complete Ensemble Empirical Mode Decomposition with Adaptive Noise (CEEMDAN) combined with Sample Entropy (SE) and a soft-hard compromise wavelet threshold to remove superficial interference information. Subsequently, the data is fed into a parallel network of Graph Convolutional Networks (GCN) and Bidirectional Long Short-Term Memory (BiLSTM) to extract and fuse spatio-temporal features. Furthermore, a hard-parameter sharing MTL framework is constructed to fully mine the coupling features among multivariate loads. An attention mechanism is introduced to dynamically adjust the weights of the loss functions in MTL, thereby achieving comprehensive excavation of deep load correlation features through a series of measures. Finally, experimental validation using the multi-load dataset of the comprehensive energy system at Arizona State University’s Tempe campus. The results demonstrate that the Weighted Mean Absolute Percentage Error (WMAPE) of the proposed forecasting model reaches 2.00%, demonstrating higher prediction accuracy than the other models in comparative experiments.

Paper ID: 330

Numerical and experimental characterization of 3d-printed hybrid auxetic metamaterials in tpu for sustainable applications

Heisei Dweyne Mansanadez[1,2], Aristotle Ubando[1,2,3]

[1]Department of Mechanical Engineering, De La Salle University, 2401 Taft Avenue, 1004 Manila, Philippines; [2]Thermomechanical Analysis Laboratory, De La Salle University – Manila: Laguna Campus, LTI Spine Road, Laguna Blvd, Biñan, Laguna 4024, Philippines; [3]Center for Engineering and Sustainable Development Research, De La Salle University, 2401 Taft Avenue, 1004 Manila, Philippines;
Email: heisei_mansanadez@dlsu.edu.ph

Abstract:

Auxetic metamaterials exhibit a negative Poisson's ratio, a property not commonly found in nature. The periodic and geometric design of these metamaterials enables tuning of their mechanical properties, making them applicable to a wide range of applications. Despite the development of hybridized auxetic designs in literature, such as the hybrid re-entrant hexagonal and chiral, there are limited studies on their simulation and experimental validation using elastic 3D printing material, such as thermoplastic polyurethane (TPU), which is capable of being remelted and reused. This study aims to address that gap by simulating re-entrant hexagon, chiral, and a hybrid of both metamaterials at the unit cell scale in ANSYS with mesh independence testing, followed by 3D printing and experimental validation using a universal testing machine for uniaxial compression. The specific energy absorption (SEA) and specific stiffness will be compared between designs. The elastic hybrid metamaterial design is expected to combine the re-entrant and chiral deformation for a potential increase in the SEA and stiffness performance, but this may not be the case at matched relative densities, which can be tuned through varying the strut thickness. The results of the study will aid in characterizing elastic metamaterial geometries that can have a potential impact on more lightweight, high-energy absorption and stiffness materials for aerospace, automotive, and other mechanical energy transfer applications.

Paper ID: 331

Extreme climate shocks, local fiscal adjustment, and the choice of buffer mechanisms

Qingbin Guo, Zhiyao Mo, Jing Liu
Hainan University, China;
Email: gqb@hainanu.edu.cn

Abstract:

The increasing frequency of extreme climate events exacerbates local fiscal vulnerability, yet little is known about their transmission into public finance and how fiscal buffers shape dynamic outcomes. Using prefecture-level panel data and gridded meteorological data in China, this paper constructs city-level datasets covering four extreme climate shocks (floods, heatwaves, droughts, and strong winds) to systematically examine their fiscal impacts empirically and through structural simulation. Results show that extreme climate shocks significantly suppress both local fiscal revenue and expenditure, with a stronger contraction on revenue. On the revenue side, shocks erode fiscal sources by reducing industrial and agricultural output. On the expenditure side, they reallocate resources toward emergency and social protection such as social security, agriculture and forestry spending while crowding out development-oriented spending such as science and technology spending. Shocks also widen fiscal deficits and increase debt pressure. These findings are robust. Further, a DSGE model with scenario comparisons reveals that while real output effects are short-lived, fiscal consequences exhibit stronger inter-temporal persistence. Among policy responses, regular carbon tax support shows greater institutional advantages than debt or transfer payment support in alleviating fiscal space contraction, stabilizing development-oriented expenditure, and restraining debt accumulation. Overall, this paper provides empirical and theoretical foundations for understanding the fiscal transmission of extreme climate risks and enhancing local fiscal resilience.

Paper ID: 332

Designing Viable SAF Systems for the Philippines: A Techno-Economic Analysis of FT-SPK, HEFA-SPK, and CH-SK Pathways

Mac Rosales, James David Abiog, Guada Altea Erin Layugan, Kathleen Aviso
De La Salle University, Philippines;
Email: mac.rosales@dlsu.edu.ph

Abstract:

The Philippines is advancing toward net-zero aviation targets by leveraging its significant feedstock potential for Sustainable Aviation Fuel (SAF). As efforts to formalize the national SAF roadmap and infrastructure of the country progress, local institutions continue developing and evaluating viable SAF pathways under local conditions. This study presents a technoeconomic analysis (TEA) of three ASTM 7566-accredited pathways tailored to the Philippine supply chain: Fischer-Tropsch Synthetic Paraffinic Kerosene (FT-SPK), Hydroprocessed Ester and Fatty Acids Synthetic Paraffinic Kerosene (HEFA-SPK), and Catalytic-Hydrothermolysis Synthesized Kerosene (CH-SK). Based on plant designs for 50,000 MT/y feedstock capacity, results indicate SAF yields of 1,504.31 MT (3.01%) for FT-SPK, 4,137.60 MT (8.28%) for HEFA-SPK, and 2,900.52 MT (5.80%) for CH-SK. Payback periods ranged from 2.55 to 9.82 years, with HEFA-SPK demonstrating the strongest economic performance which are consistent with reference studies. These findings further underscore the viability of SPK for fuel blends to further reduce costs, showing a strategic mechanism for the smooth transitioning of the Philippine commercial aviation industry toward carbon neutrality.

Paper ID: 333

The comprehensive benefits and distributional inequality of reclaimed water in China

Changqing Xu, Tianyu Jia, Wei Lin, Yuqiao Lan
Beijing Institute of Technology, China, People's Republic of;
Email: xcq@bit.edu.cn

Abstract:

Reclaimed water is increasingly recognized as a critical nonconventional water source for alleviating water scarcity, yet its future potential and systemic role remain insufficiently understood under different socioeconomic development pathways. This study develops a reclaimed water utilization potential assessment model to evaluate its future evolution, associated benefits, and spatial inequality in China from 2025 to 2050 under multiple scenarios. Results show that national reclaimed water potential exhibits a persistent growth trend with marked differences across scenarios, reaching the highest level under SSP5. The growth is primarily supported by sustained increases in industrial wastewater, while domestic wastewater shows a peak and decline pattern. Comprehensive benefits are dominated by resource conservation, with environmental improvement and ecosystem service values exhibiting strong regional heterogeneity. Meanwhile, reclaimed water distribution remains more unequal than conventional water resources, with a population-weighted Gini coefficient exceeding 0.40. These findings highlight the importance of incorporating wastewater structure, spatial allocation, and cross-regional coordination into reclaimed water planning to enhance water system resilience and sustainability.

Paper ID: 338

From flexibility gaps to resilience gains: coordinated resource planning for high-renewable power systems

Yang Bai, Lijun Wang, Zhanpeng Shu

China University of Petroleum Huadong, China, People's Republic of;

Email: ybai@upc.edu.cn

Abstract:

High-renewable power systems are increasingly constrained not by installed capacity alone, but by whether sufficient flexibility can be delivered at the right time, in the right direction, and for a sufficient duration under compound supply-demand shocks. Existing flexibility-planning studies often evaluate resource adequacy, storage deployment or demand response in isolation, while resilience studies usually focus on post-shock performance without linking it back to long-term flexibility-resource configuration. This separation makes it difficult to identify which resources actually remove operational bottlenecks, which only reduce short-duration deficits, and how coordinated strategies perform when renewable output losses and load surges occur simultaneously. This study develops an integrated framework that couples long-term flexibility-resource planning with short-term emergency resilience assessment for a high-renewable power system. Using representative seasonal profiles and stress-test scenarios for China’s low-carbon transition, we quantify upward and downward flexibility gaps, model heterogeneous source-side, storage-side and demand-side resources, and evaluate six emergency strategies using a unified post-dispatch shortfall series. Results show substantial seasonal flexibility deficits, with minimum net flexibility margins of -493.66 GW, -523.74 GW and -433.99 GW in winter, spring-autumn and summer, respectively. Under a major compound shock, the pre-dispatch peak shortfall reaches 1852.56 GW and the unserved energy reaches 19160.16 GWh/event. Single-resource strategies reduce losses but cannot eliminate residual deficits, whereas coordinated dispatch reduces the peak shortfall to 725.53 GW and lowers unserved energy to 1088.17 GWh/event. Sensitivity analysis further identifies coal flexibility, battery duration, demand-response availability and shock intensity as key determinants of system resilience. The findings suggest that flexibility planning should move beyond capacity expansion toward resilience-oriented resource portfolios that value availability, response speed, duration and dispatchability. For power-system governance, this implies coordinated investment in transitional thermal flexibility, long-duration storage, demand-side flexibility markets and stress-test-based planning standards.

Paper ID: 361

Apparent coating–foil adhesion strength of spent LFP and NCM cathodes for lithium-ion battery recycling

Bentang Arief Budiman[1,2], Rhainna Rheizkhira Reflin[1], Richard Diaz Alorro[3]

[1]Faculty of Mechanical and Aerospace Engineering, Institut Teknologi Bandung, Jl. Ganesha No. 10, Bandung 40132, Indonesia; [2]National Center for Sustainable Transportation Technology, Institut Teknologi Bandung, Jl. Ganesha No. 10, Bandung 40132, Indonesia; [3]WA School of Mines: Minerals, Energy and Chemical Engineering, Faculty of Science and Engineering, Curtin University, Kent Street, Bentley, Perth WA 6102, Australia;

Email: bentang@itb.ac.id

Abstract:

Adhesion debonding between the cathode active material coating and the current collector foil is one of the common failure mechanisms in lithium-ion batteries, affecting electrochemical performance, mechanical integrity, and battery recycling efficiency. This study investigates the coating–foil interfacial adhesion of spent cathodes recovered from end-of-life LFP- and NCM-based batteries after prolonged service. The apparent adhesion strength was evaluated using a tensile pull-off test by measuring the peak stress associated with coating detachment. Double-sided cathode electrode sheets were sandwiched between two flat acrylic substrates. One side was bonded using a liquid adhesive to provide strong support and prevent premature detachment, while the opposite side was bonded using a gel adhesive so that detachment was expected to occur preferentially from the tested coating side. Preliminary results show that spent LFP cathode specimens had an average apparent adhesion strength of 0.28 MPa, while spent NCM specimens averaged 0.20 MPa. These values are approximately 91% and 94% lower, respectively, than the 3.11 MPa adhesion strength reported for dry Ni-Co-based cathodes in previous studies. This comparison should be interpreted cautiously because of differences in cathode chemistry, service condition, sample preparation, and testing method. The lower measured adhesion strengths indicate weakened interfacial bonding in spent cathodes, which may affect mechanical coating separation during recycling. These findings provide preliminary insight for developing lithium-ion battery recycling strategies based on actual end-of-life battery conditions.