CONECT 2026

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RIGA TECHNICAL UNIVERSITY

XIX International Scientific Conference of Environmental and Climate Technologies

BOOK OF ABSTRACTS

12–15 May 2026 | Riga, Latvia

CONECT 2026
XIX International Scientific Conference of
Environmental and Climate Technologies

BOOK OF ABSTRACTS

Riga Technical University
Institute of Energy Systems and Environment
Adress: 12-k1 Azenes iela, Riga,
LV-1048, Latvia
Phone: +371 670 899 23
E-mail address: conect@rtu.lv, ect@rtu.lv
Web page: www.conect.rtu.lv

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CONECT 2026
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LAFLORA
Peat for demanding gardeners!

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CONECT 2026

XIX International Scientific Conference of Environmental and Climate Technologies

The International Scientific Conference on Environmental and Climate Technologies (CONECT) is an annual event organized by Riga Technical University that has been held since 2008. Over the years, the conference has developed into a recognized platform that brings together scientists, researchers, doctoral students, and industry professionals from across the globe to exchange knowledge and foster collaboration in sustainable development.

CONECT aims to promote the dissemination of the latest scientific achievements in energy systems, environmental engineering, and climate technologies. The conference provides an opportunity not only to present research results but also to discuss emerging challenges and innovative solutions related to climate change mitigation, resource efficiency, and sustainable energy transitions.

Each year, the conference gathers a diverse international audience, typically representing more than 25 countries, creating a dynamic environment for interdisciplinary exchange and networking. The program includes **plenary sessions, thematic panels, poster presentations, workshops, and networking events**, enabling participants to engage with leading experts and explore new research directions.

The thematic scope of CONECT reflects current global priorities in environmental and climate research. Key topics include, but are not limited to,

- renewable energy technologies,
- energy efficiency,
- district heating systems,
- bioeconomy,
- environmental and energy policy frameworks,
- climate communication,
- sustainability
- resilience.

Through its long-standing tradition, international reach, and focus on pressing global challenges, CONECT continues to serve as an important meeting point for advancing knowledge, fostering innovation, and supporting the transition to a sustainable, climate-resilient future.

WE WISH YOU ALL A FRUITFUL CONFERENCE!

CONECT 2026 Conference Organising Committee

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RTU IESE

The Institute of Energy Systems and Environment.

RTU IESE is one of the leading research and academic units at Riga Technical University, dedicated to advancing knowledge and innovation in energy, environment, and sustainability. The Institute plays a key role in interdisciplinary research by integrating engineering, environmental science, and socio-economic perspectives to address complex challenges related to climate change and sustainable development.

IESE focuses on developing innovative solutions for energy system transformation, environmental protection, and resource efficiency. Its research activities cover a wide range of topics, including renewable energy technologies, district heating and cooling systems, energy efficiency, circular economy, bioeconomy, climate policy, and environmental impact assessment. Special attention is given to the integration of technological solutions with policy frameworks and behavioral aspects, ensuring that research outcomes are applicable in real-world contexts.

The Institute is actively involved in international research collaboration and participates in numerous European and global projects, including Horizon Europe, LIFE, and other funding programs. Through these initiatives, IESE contributes to the development of cutting-edge methodologies and tools for sustainable energy planning, climate mitigation strategies, and environmental governance. Collaboration with academic institutions, industry partners, and public sector organizations strengthens the practical relevance and impact of the Institute's work.

In addition to research, IESE is strongly engaged in higher education and capacity building. The Institute offers study programs at bachelor's, master's, and doctoral levels, fostering the next generation of specialists in energy and environmental technologies. Students are actively involved in research projects, gaining hands-on experience and contributing to innovative solutions.

IESE also plays a significant role in knowledge transfer and public engagement. By organizing international conferences, workshops, and training activities—such as the CONECT conference—the Institute promotes the dissemination of research results and facilitates dialogue between scientists, policymakers, and industry stakeholders.

With its strong scientific foundation, international orientation, and commitment to sustainability, the Institute of Energy Systems and Environment continues to contribute to the transition towards a climate-neutral and resource-efficient future.

The Journal of Environmental and Climate Technologies, published by RTU IESE, is an international scientific journal that offers global exposure for original research and innovations.

It covers a variety of topics for all aspects of Environmental science:

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- Cleaner Production and Industrial Symbiosis,
- Ecodesign and Life Cycle Assessment,
- Climate Technologies,
- Climate Change and Resilience,
- Circular Economy,
- Environmental Monitoring and Remediation.

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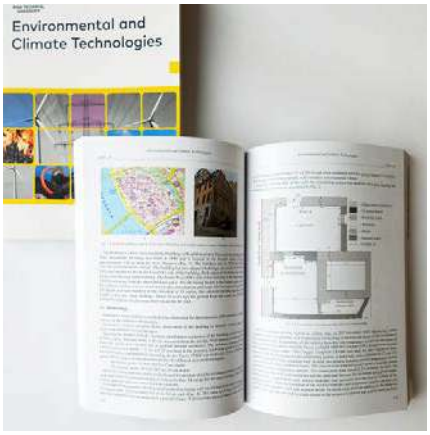

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SUSTAINABLE BUILDING SOLUTIONS FOR GENERATIONS TO COME

SUSTAINABILITY
THAT WORKS

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FOR FUTURE GENERATIONS

As a family business in its fifth generation, we are aware of our responsibility towards people, nature, environment and climate. We think across generations and place particular focus on the sustainability of our building material solutions.

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Together with our partners, we constantly strive to be two steps ahead. We consistently focus on the research and development of new products and procedures and have high quality standards. We drive innovation and growth in a targeted manner.

MORE THAN THE SUM OF OUR PARTS

Within the building materials group we have a keen sense of cohesion based on the exchange of knowledge and procedures. The focus is on the continuous support and growth of our employees and a long-term collaboration with our customers.

SCHWENK

THE FUTURE OF PEATLANDS: FROM EXTRACTION TO INNOVATION

LAFLORA

LAFLORA
Peat for demanding gardeners!

LAFLORA

SIA Laflora is a peat extraction and processing company delivering a comprehensive, sustainability-oriented production cycle – from land preparation and peat harvesting to high value-added products and long-term land restoration through recultivation.

Sustainability is at the core of Laflora's strategy, with a strong focus on people, innovation, and evidence-based solutions that ensure responsible and efficient operations.

LAFLORA

High-Quality Peat Substrates

Laflora produces peat substrates – KKS designed to provide optimal growing conditions for plants. The company has developed a range of substrate products suitable for both professional horticulture and amateur gardening.

Research-Driven Decisions

At Laflora, decisions are driven by research and continuous innovation. Pilot sites support scientific studies and ongoing development, enabling the company to advance technologies in:

- **Environmental management**
- **Materials science**
- **Production efficiency**
- **Sustainable land stewardship**

These efforts drive innovation, support responsible growth, and contribute to environmental protection.

Future Vision: Green Industrial area

Laflora's future vision is to create an integrated, environmentally responsible Green Industrial area – a sustainable ecosystem that combines advanced production, innovation, and circular resource use, setting new standards for the peat industry.

www.laflora.lv

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01

ENERGY EFFICIENCY, ENERGY SYSTEMS (DISTRICT HEATING)

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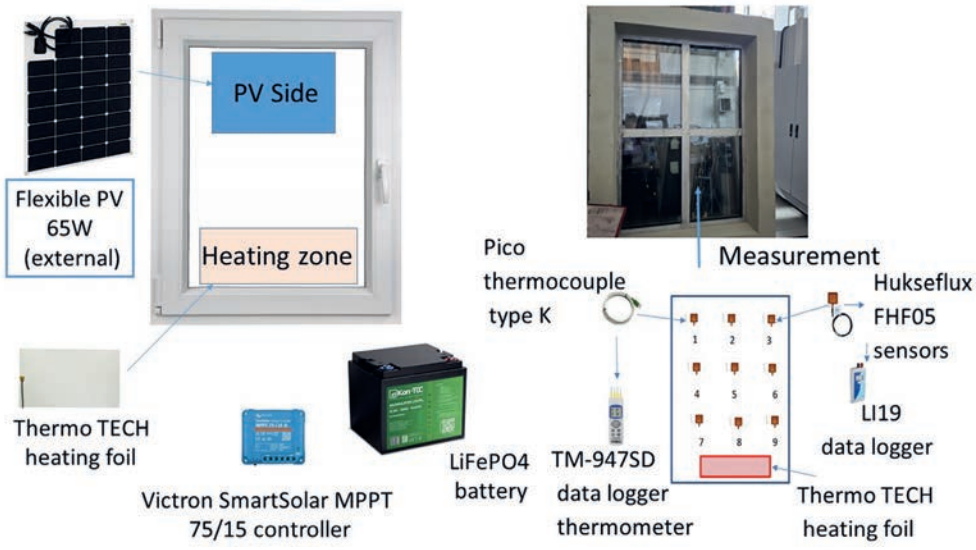
AUTONOMOUS PV-POWERED SMART WINDOWS: ACTIVE GLASS HEATING IN NZEB APPLICATIONS

Hanna KOSHLAK*

Kielce University of Technology, Aleja Tysiąclecia Państwa Polskiego, 7, 25-314 Kielce, Poland
* ***Corresponding author.*** *Email address: hkoshlak@tu.kielce.pl*

Abstract – The building sector is a primary contributor to global energy consumption, with windows identified as the least efficient component of the building envelope. This study investigates the thermal performance of an "active" smart window system featuring an integrated electrical heating element (Thermo TECH) powered by an autonomous renewable energy microgrid. The research was conducted in two stages. First, experimental trials were performed in a specialised dual-zone climatic chamber at the Kielce University of Technology to evaluate heat flux dynamics across an external temperature range of –25 °C to +5 °C. Second, in-situ measurements were carried out on a physical installation at the university premises to account for real-world meteorological fluctuations. The results demonstrate that precise modulation of the heating element enables the achievement of a "near-zero thermal balance," effectively transforming the window from a thermal bridge into a thermally neutral element. While active heating increases external heat dissipation, it effectively eliminates the "cold pane" effect, raising the internal surface temperature from +12 °C to +18 °C at an outdoor temperature of –25 °C. The study concludes that integrating PV modules with active window heating offers a viable pathway for achieving NZEB standards by providing by providing a self-sustaining solution for energy loss reduction.

Keywords – Active window heating; energy balance; photovoltaics; smart windows



Schematic layout of the monitoring and heating smart window system:
(a) the functional power management and active heating system components in-situ natural experiment configuration; (b) the laboratory measurement configuration for climatic chamber testing

ACKNOWLEDGEMENT

This research was funded in whole or in part by the National Science Centre, Poland, DEC-2025/09/X/ST8/00339, "Integracja fotowoltaiki z oknami ogrzewanymi elektrycznie: pilotażowe badanie w celu zwiększenia efektywności energetycznej budynków"/ "Integrating photovoltaics with electrically heated windows: a pilot investigation for enhanced building energy efficiency." For the purpose of Open Access, the author has applied a CC-BY public copyright licence to any Author Accepted Manuscript AAM version arising from this submission.

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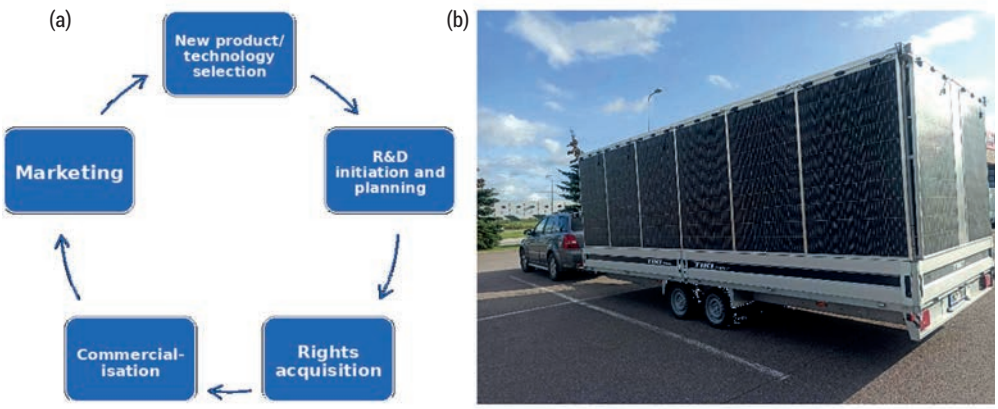
INNOVATIVE MOBILE POWER STATION FOR FIELD ROBOTICS: SYSTEM DESIGN AND COMMERCIAL PERSPECTIVES

Olga LIIVAPUU[1*], Yevhen IHNATIEV[2], Jüri OLT[3]

[1–3] *Estonian University of Life Sciences, Fr. R. Kreutzwaldi 56, 51006, Tartu, Estonia*

[*] ***Corresponding author.*** *Email address: olga.liivapuu@emu.ee*

Abstract – Innovation plays an important role in all fields, including agriculture. Intellectual property, specifically industrial property is a key driver of innovation and economic growth. Effective commercialization of industrial property can stimulate economic activity by attracting investment, creating additional jobs, and fostering the development of new products and services. This research examines the commercialization prospects of a novel autonomous, mobile, environmentally friendly energy station developed at a university. The process begins with obtaining industrial property protection rights and understanding their management, which involves a series of legal procedures, and then initiating technology transfer. This is an academic technology transfer from a university to a commercial enterprise. To support this process, a licensable technology portfolio must be compiled, centered on the licensing asset, which may include one or more patents, utility models, and know-how. Naturally, the selling points of the commercialized product or technology must be clearly articulated. The mobile energy station comprises a solar power plant (non-dispatchable, primary) with a maximum total power of 6.8 kW, a biomethane-powered generator (dispatchable, secondary), an energy storage system with a total capacity of 14.4 kWh, and a rapid battery swapping and charging device for an agricultural robot. This hybrid solution (solar + generator) ensures continuous operation even under adverse weather conditions. The battery swapping and charging device includes a platform alignment mechanism, a powered trolley for transferring the battery, and an automated locking and unlocking mechanism. The energy station is automated and controlled by a programmable logic controller (PLC) and several embedded microcontrollers. The central PLC (SIMATIC) coordinates process-control functions: operation of the solar tracking drives, battery state of charge, generator operation, and wireless communication with approaching robots.



Product commercialisation model (a) and mobile energy station (b)

Keywords – Autonomous systems; environmental protection; intellectual property; off-grid power supply; renewable power systems; sustainable innovation; techno-economic assessment

ACKNOWLEDGEMENT

This work has been supported by the Estonian State Shared Service Center within the funding program Institutional package measure for R&D institutions and higher education institutions (ASTRA+ action 3) project "Development of the Innovation Readiness of an Autonomous Mobile Energy Generation Station" F250125MIBT nr 11.3-1/25/3697.

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WASTE HEAT UTILISATION FOR THERMAL MANAGEMENT OF OUTDOOR BATTERY ENERGY STORAGE IN COLD-CLIMATE MICRO-PV SYSTEMS

Heiki LILL*

Estonian University of Life Sciences, F. R. Kreutzwaldi 1, Tartu, 51006, Estonia
* ***Corresponding author.*** *Email address: Heiki.lill@emu.ee*

Abstract – In Estonia, a micro-producer is defined by the distribution system operator *Elektrilevi* as an electricity producer operating a three-phase generating unit with a maximum installed capacity of up to 15 kW. Over recent years Estonia has experienced rapid growth in photovoltaic (PV) generation connected to the distribution network, accompanied by a substantial increase in installed solar capacity. By the end of 2024, cumulative PV capacity connected to the Estonian power system had exceeded by approximately 1.3 GW, following a record annual addition of around 513 MW during the same year. In parallel, the number of electricity producers connected to the *Elektrilevi* distribution network had risen to over 22 800 by 2025, the vast majority of which are PV-based installations. Concurrently, electricity market conditions have evolved, so that periods of high solar generation increasingly coincide with low or even negative wholesale electricity prices. This development has incentivised producers to seek solutions for temporal shifting of electricity exports to more favourable price periods, most commonly through the deployment of battery energy storage systems. However, many Estonian micro-producers face significant barriers to battery adoption, as PV installations are frequently located away from buildings and most commercially available battery systems are not recommended for outdoor operation under sub-zero temperature conditions, thereby complicating year-round use in cold climates. This study investigates the hypothesis that internally generated waste heat – arising from inverter (DC/AC) conversion losses and battery charge–discharge inefficiencies could be sufficient to maintain the thermal conditions required for an outdoor battery facility located adjacent to a PV installation. The objective is to assess whether such a passive or semi-passive thermal management approach is technically feasible and economically viable for micro-producers operating under Estonian climatic conditions

Keywords – Distributed generation; electricity price volatility; heat dissipation; passive heating; sub-zero operation

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EXISTING POWER PLANT DECARBONIZATION IN LATVIAN REGION

Giovanni BRUMANA[1*], Gatis BAZBAUERS[2], Giuseppe FRANCHINI[3], Elisa GHIRARDI[4], Madara RIEKSTA[5]

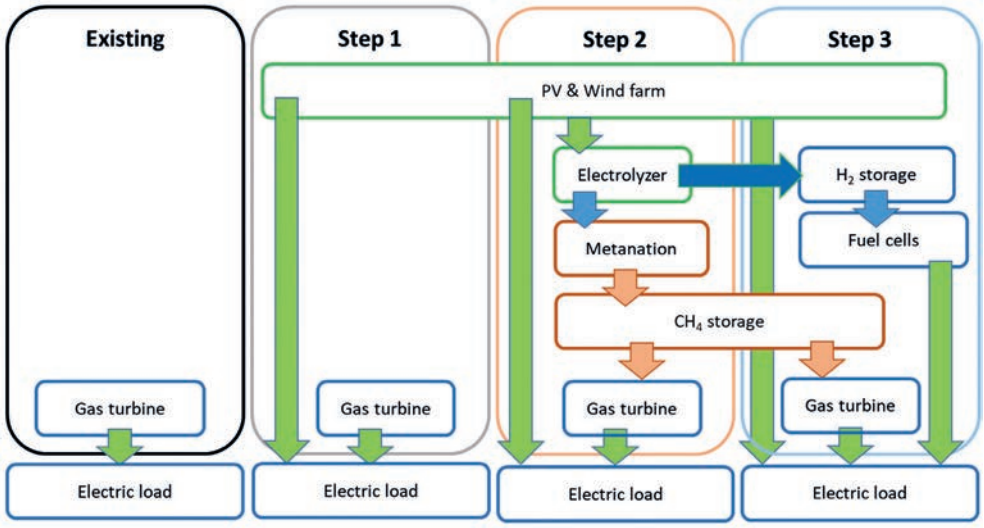
[1,3,4] *Department of Engineering and Applied Sciences, University of Bergamo, 5 Marconi Street, Dalmine 24044, Italy*

[2,5] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, LV-1048, Latvia*

[5] *JSC Rigas Siltums, Cesu street 3a, LV-1012, Latvia*

[*] ***Corresponding author.*** *E-mail address: giovanni.brumana@unibg.it*

Abstract – The global rise in energy demand is compelling the energy sector to reassess the transition from fossil fuel-based systems to renewable energy sources. However, the variability of non-dispatchable generation poses challenges to grid stability and to reliably meeting nighttime demand. Moreover, a seasonal shift from summer to winter production is necessary to further increase the share of renewable energy. Starting from previously developed model, the work proposes a path to decarbonize an existing power plant in Riga adopting a techno-economic optimization. Starting from a gas turbine power plant the 100 % decarbonization is achieved in different steps. The work aims to identify the optimal combination of power generation and storage technologies to supply the electricity demand of a city in the Latvian region with a peak load of 100 MW and an annual consumption of 700 GWh considering the best techno-economic solution. The decarbonisation path, proposed in Fig. 1, combines existing conventional gas-fired power plant integrated with the most cost-effective renewable generation technologies, namely photovoltaic systems and wind turbines adopted in Step 1. By this way the decarbonization reach only 35 % of the annual load and represents the actual achievement in most European country. To fully decarbonize power generation, the only



Decarbonization steps for existing power plant

way is to supply green methane to the power plant. The proposed solution, in step 2, included methanation starting from CO_2 capture and hydrogen from renewable electricity surplus. Step 2 reach 100 % of renewable energy sources but the price reach 0.24 EUR/kWh. The step number 3 proposes the most advanced hydrogen storage with fuel cell ion the aim of gas turbine substitution at the end of gas turbine operation reaching a 0.19 EUR/kWh. The analysis is based on TRNSYS numerical modelling combined with multivariable particle swarm optimization to minimize the levelized cost of electricity (LCOE). Overall, the findings highlight the critical role of the hydrogen system, whose capacity is approximately twenty times greater than that of the methane system.

Keywords – Decarbonization; energy storage; hydrogen, renewables; transient simulation

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DEVELOPMENT OF A HYBRID BIDIRECTIONAL HEAT TRANSFER STATION FOR DECENTRALIZED FEEDING OF SOLAR ENERGY INTO DISTRICT HEATING NETWORKS

Fabian Stefan ACHILLES[1], Alois RESCH[2*]

[1,2] *University of Applied Sciences Upper Austria, School of Engineering, Stelzhamerstrasse 23, A-4600 Wels, Austria*

* ***Corresponding author.*** *Email address: alois.resch@fh-ooe.at*

Abstract – As a result of the continuous expansion of district heating networks (DHNs) in Austria and their growing importance for centralized heat supply, there is an increasing demand for innovative solutions to decarbonize these systems, particularly under partial- and low-load operating conditions. Moreover, the rising complexity and extension of DHNs lead to hydraulic and thermal limitations in certain network sections, which in some cases prevent the connection of additional consumers. One potential solution to address both challenges is the decentralized integration of so-called prosumers equipped with their own solar thermal systems (ST) or photovoltaic (PV) installations including power-to-heat components. This integration would enable surplus solar energy to be fed into DHNs, thereby increasing overall system utilization and reducing system payback periods for both solar systems, ST and PV. Especially, it provides an alternative to feeding PV electricity into the electrical grid, which becomes technically and economically more challenging. However, there is a lack of technical solutions to connect a potential prosumer to a DHN in a way that heat can be transferred in both directions. Therefore, the research work presented by this paper aims to contribute to overcome this shortage of bidirectional heat transfer stations (HTS). Based on the current state-of-the-art, a new concept for a hybrid bidirectional HTS was developed, which is capable of feeding excess solar energy from decentralized ST or PV systems into a DHN. Various hydraulic concepts were designed and evaluated, followed by engineering tasks and material selection. A prototype of the novel hybrid bidirectional HTS was constructed by modifying an existing unidirectional HTS, and performance measurements were conducted in the laboratory. Both the supply operation at 20 kWth and feed-in operation at 10 kWth were successfully tested. The measurement data confirmed that the target temperatures of 80 °C in the flow and 55 °C in the return of the emulated DHN as well as 70 °C in the flow and 50 °C in the return of the building side were achieved. The feed-in operation could almost be kept constant at 10 kWth, even during a sudden load change. Based on the results and experience gained during the construction and following testing phases, valuable insights were obtained for the further development of a market-ready system for commercial applications in the long-term perspective.

Keywords – Bidirectional heat transfer station; decentralized feed-in; district heating network; integration of excess solar energy; surplus energy applications

ACKNOWLEDGEMENT

This work is supported by research subsidies granted by the Government of Upper Austria within the research project “Comprehensive Energy Storage” (Research Grant Wi-2022-600132/7-Au).

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A BUSINESS MODEL FOR AGGREGATORS INVESTING IN ENERGY COMMUNITIES

Gregorio Morosinotto*

CRIEP-University of Padua, Via del Santo 33, Padova, 35123, Italy

* ***Corresponding author.*** *Email address: gregorio.morosinotto@unipd.it*

Abstract – Distributed Energy Resources (DERs) are increasingly deployed as a result of climate change mitigation policies, since the expansion of renewable energy penetration is widely recognized as a key driver of the transition and a necessary condition for achieving emission reduction targets. Among the most effective frameworks for fostering DER deployment are Energy Communities (ECs), which enable households to coordinate energy production and consumption in order to maximize efficiency through self-consumption mechanisms. Despite their growing relevance, the role of energy companies, particularly Aggregators, within Energy Communities remains insufficiently explored. Specifically, it remains unclear how Aggregators can effectively support community members throughout the aggregation process in overcoming key barriers, including insufficient technical knowledge of microgrid operations, legal and bureaucratic uncertainties, constrained access to finance, and weak incentive schemes, while generating economic value. This study aims to assess whether Aggregators can play a constructive role in supporting their creation and operational management within the Italian regulatory and market framework. To address these challenges, a novel business model is proposed, delineating the Aggregator's position within the energy supply chain, the energy management tasks it performs, and the conditions under which its investment activity can achieve financial sustainability. The analysis explicitly accounts for public incentive schemes, geographic asymmetries, the cost of capital in the energy sector, and uncertainty in electricity prices. A case study is developed, and a set of simulations based on alternative self-consumption functions is conducted to identify the optimal level of public subsidy, whose target value is currently not specified by the regulatory authority, and to assess financial performance under different price inflation and debt leverage scenarios.

Keywords – Ancillary services; Distributed Energy Resources (DERs); energy infrastructure investing; energy flexibility; electricity markets, energy self-consumption function

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A STRUCTURED LCA METHODOLOGY FOR COMPARATIVE ENVIRONMENTAL ASSESSMENT OF DISTRICT HEATING PIPE MATERIALS

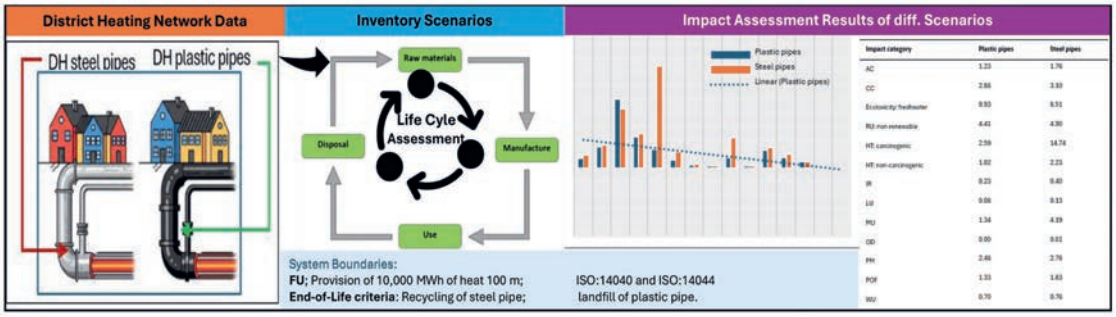
Hesham ALI[1*], Maryam KHALIQ[2], Janika LAHT[3], Anna VOLKOVA[4]

[1–4] *Department of Energy Technology, Tallinn University of Technology, Ehitajate Tee 5, 19086 Tallinn, Estonia*

[*] ***Corresponding author.*** *Email address: Hesham.ali@taltech.ee*

Abstract – The environmental assessment of district heating and energy distribution systems is widely focused on carbon equivalent emissions related to energy generation units, while the environmental impacts associated with distribution materials are seldom addressed. In particular, the selection of pipe materials is often excluded from system-level assessments, despite their long service life and material intensity. This study presents a structured methodological approach for the comparative life cycle assessment of district heating pipe materials, focusing on steel and plastic pipes under identical functional conditions. The assessment is based on a functional unit defined as the transport of the same amount of thermal energy over a fixed distribution distance, ensuring functional equivalence between the compared systems. Different end-of-life scenarios were evaluated in order to assess their influence on comparative results, including recycling allocation for steel pipes and landfill disposal assumptions for plastic pipes. The results demonstrate that material choice and end-of-life modeling have a noticeable effect on the environmental performance of district heating pipe systems across several impact categories. Steel pipes generally show higher impacts related to resource use and toxicity, while plastic pipes exhibit lower impacts in most categories, including greenhouse gas emissions, but are more sensitive to disposal assumptions. The proposed approach provides a transparent basis for material assessment in energy distribution systems and supports more informed decision-making in sustainable district heating design.

Keywords – Comparative analysis; district heating infrastructure; end-of-life modeling; environmental impact assessment; functional unit definition; recycling allocation



Methodological framework for the comparative assessment of district heating pipe materials

ACKNOWLEDGEMENT

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ENERGY HUB CONCEPTUAL IMPROVEMENT WITH HOUSEHOLD INVOLVEMENT

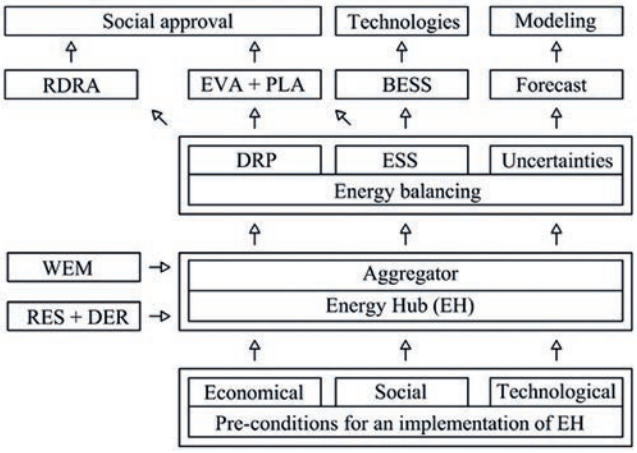
Haralds SIKTARS[1*], Vladimirs KIRSANOVS[2], Ivars VEIDENBERGS[3], Ieva PAKERE[4]

[1-4] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia*

[*] ***Corresponding author.*** *Email address: haralds.siktars@rtu.lv*

Abstract – Existing energy systems in the global energy market are historically based on the centralized generation using fossil fuels, which has been largely unchanged due to the high impact of lobbyists in fossil resource market and geopolitical situation. However, due to the increased renewable energy resource implementation in the energy portfolio, shift to more decentralized energy production and distribution is increasing. New energy system concepts emerge like energy hubs (EH) and demand response programs (DRP), which have been increasingly studied for energy sector improvement, which allows to adapt demand to the supply. Supply is fluctuating due to discontinuity of solar and wind energy. Most recent reviews regarding energy hubs and energy sector are highlighting the various solutions for energy supply balancing, which include residential and industrial sector involvement into the demand response program, using household appliances, electric vehicles and other shiftable electricity consumers as well as other demands like heat, natural gas and domestic. Energy management in energy hub is organized by aggregators, which are responsible for most optimal distribution, storage and price of electricity, prioritizing locally generated power over imported electricity from centralized units. Such approach allows to exploit he locational value of energy and bypass the transfer losses via conventional distribution network. Such losses are more impactful during the peak hours, which increases the electrical load of the wire, thus increasing the marginal losses. High importance has social approval for energy system development to energy hubs, thus involving consumers more than some might be interested in. Survey will be conducted to determine the opinion and limitations of society in Latvia. Aim of this research is to improve the energy hub concept modeling and social aspects and meanwhile address the main problematics of the currently developed systems, especially based on household involvement and sizing restrictions.

Keywords – Aggregator; district heating; Demand Response Program; grid balance; Multi-Energy System; smart home; waste heat



Framework for Energy hub modeling and conceptualization

ACKNOWLEDGEMENT

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ENERGY HUB INTEGRATION POSSIBILITIES IN ENERGY PORTFOLIO OF LATVIA BASED ON EXAMPLES IN EUROPE

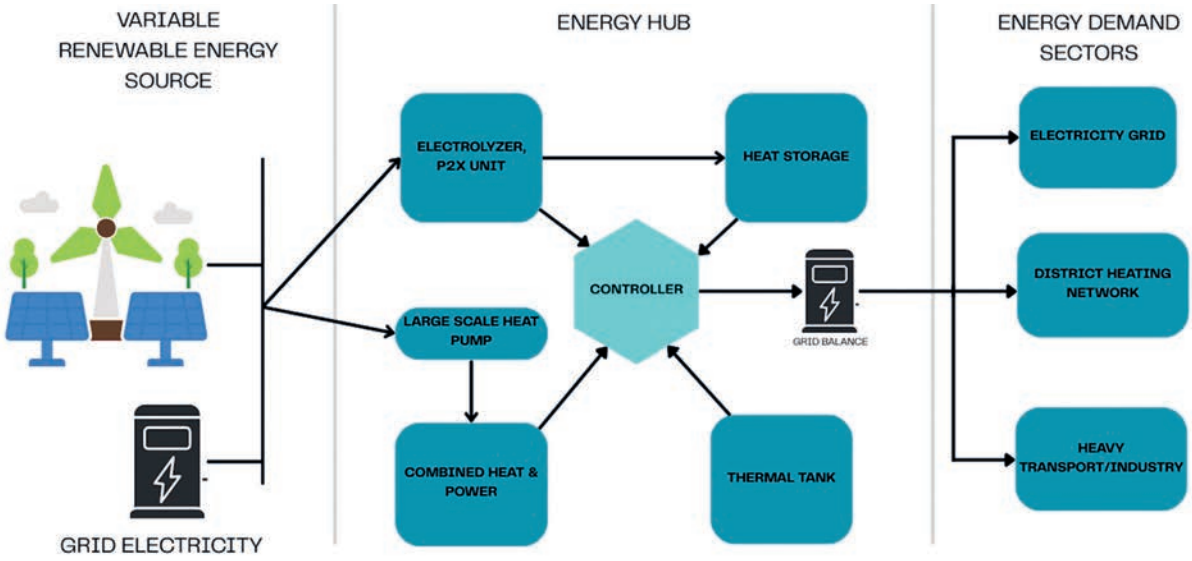
Marta VIEGLINA[1*], Haralds SIKTARS[2], Vladimirs KIRSANOVS[3], Ivars VEIDENBERGS[4]

[1–4] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia*

[*] ***Corresponding author.*** *Email address: haralds.siktars@rtu.lv*

Abstract – Increasing energy demand, rising greenhouse gas emissions and limited fossil fuel reserves are creating critical global energy challenges. To address these issues, a fundamental shift in energy management is needed, moving towards innovative solutions like energy hubs. This concept is designed to model and optimize multi-energy systems, integrating electricity, heat and gas to achieve carbon neutrality and improve system flexibility. The research focuses on the conceptual development of energy hubs and their potential implementation in Latvia by conducting a comparative analysis of leading European examples, such as energy islands in Denmark and sector coupling projects in Germany. The methodology of the study is based on three core pillars: ESG criteria evaluation, technological parameter analysis and GIS based modeling to identify the most suitable locations for a potential energy hub implementation in Latvia. Technological investigation focuses on the synergy between conversion technologies like electrolyzers for green hydrogen and large-scale thermal storage, meanwhile allowing to introduce more RES in the energy portfolio. While the study is ongoing, preliminary comparative analysis of European examples suggests that energy hubs significantly enhance system flexibility through sector coupling, particularly by transforming surplus renewable energy into storable energy forms. The results of this study aim to provide a strategic roadmap and a spatial suitability map for the deployment of the first-generation energy hubs in Latvia, specifically considering the integration of wind and the modernization of district heating networks. The research will conclude with specific recommendations for stakeholders to facilitate a decentralized, resilient and carbon-neutral transition that aligns with European Green Deal and national energy and climate plan of Latvia.

Keywords – Energy hub; energy transition; ESG criteria; grid balance; hydrogen; multi-energy system; Power-to-X; sector coupling



Conceptual framework of an energy hub, integrating multi-energy sectors and H2 technologies

ACKNOWLEDGEMENT

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PREFABRICATED INTERIOR FAÇADE SYSTEM WITH VACUUM INSULATION PANELS AND AN ADVANCED DIGITAL WORKFLOW FOR DEEP ENERGY RENOVATION: A CASE STUDY IN SPANISH SOCIAL HOUSING

Pablo MORENO-PESTAÑA[1], Alba ARIAS[2], Mikel BARRENA-HERRÁN [3*], Olatz IRULEGI-GARMENDIA[4]

[1] *ENEDI Research Group, Department of Energy Engineering, Faculty of Engineering of Bilbao, University of the Basque Country UPV/EHU, Plaza Ingeniero Torres Quevedo 1, 48013 Bilbao, Spain*

[2–4] *CAVIAR Research Group, Department of Architecture, University of the Basque Country (UPV/EHU), Plaza Oñati 2, 20018 Donostia-San Sebastián, Spain*

[*] ***Corresponding author.*** *Email address: mikel.barrena@ehu.eus*

Abstract – The energy efficiency retrofitting of the building stock is a current effort in most European countries. Most interventions in the building envelope are carried out by adding external insulation to the façade, which modifies its composition and materiality, altering the urban landscape and contributing to a progressive loss of architectural identity. Internal insulation façade systems are less common and mainly used in high-value heritage buildings, where the main disadvantage is usually associated with the loss of internal space. However, new high-performance and thin insulation materials have appeared on the market, making their application feasible in common buildings such as social housing. This paper presents the design of a prefabricated interior façade system based on a timber frame and Vacuum Insulation Panels (VIP), incorporating space for service routing. The system can vary from 75 mm to 90 mm depending on the building's energy requirements. A comparison of interior surface loss for different business-as-usual solutions was carried out to demonstrate the reduction in insulation thickness provided by VIP panels. To develop the prefabricated façade solution, advanced digitalised processes were implemented to link the laser-scanning of the existing building, which was used to generate the BIM model, with the industrial manufacturing of the system, addressing the limitations of VIPs for onsite work. The façade system has been tested and validated in 12 social housing units in Northern Spain. The proposed solution achieves a 43.9 % reduction in surface loss compared to the business-as-usual scenario and a 36.0 % reduction relative to the high-end alternative. The optimised workflow redistributes effort from installation to earlier manufacturing phases, yet no immediate economic advantage was observed due to limited knowledge of digitalised processes; however, the approach still offers long-term potential in optimisation, waste reduction, energy savings, and assembly efficiency, providing valuable lessons for future deep renovation strategies.

Keywords – Digitalised construction workflows; interior insulation systems; social housing renovation; vacuum insulation panels

ACKNOWLEDGEMENT

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ELECTRIFICATION PATHWAYS FOR DISTRICT HEATING IN LATVIA

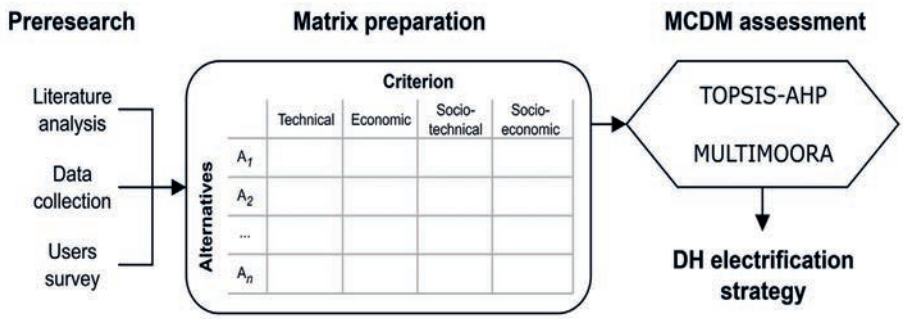
Dainis BASS[1], Oskars SVEDOVS[2*], Edgars VIGANTS[3], Vladimirs KIRSANOVS[4], Ivars VEIDENBERGS[5], Ieva PAKERE[6]

[1–6] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia*

[*] ***Corresponding author.*** *Email address: oskars.svedovs@rtu.lv*

Abstract – District heating (DH) in Latvia has a strategic role. It accounts for more than one third of final energy consumption and relies mainly on biomass. In line with diversification principles, rapid electrification is required to modernize the sector and enhance sustainability. Available electrification options for DH can be classified by device category (heat pumps or electric boilers), by capacity and grid connection type (high-capacity at the transmission grid or medium and low-capacity at the distribution grid), and, for heat pumps, by specific technology (air-to-water, ground-to-water, water-to-water). Combinations of these options constitute alternatives that must be evaluated to provide decision-makers and stakeholders with a scientifically grounded strategy. For the evaluation, a multi-criteria decision making (MCDM) assessment was selected, specifically TOPSIS-AHP and MULTIMOORA methods, with sector experts involved to assign certain criterion values and weights. TOPSIS-AHP is suitable because AHP elicits transparent and consistent expert weights, while TOPSIS ranks alternatives by distance to positive and negative ideal solutions, handling benefit and cost criterion with simple normalization. MULTIMOORA complements this by providing three complementary operators that mitigate scale effects and enable a robustness cross-check of the ranking. Although technologically simpler and higher-capacity options, such as large-scale electric boilers, are in theory more affordable and yield greater economic benefits, the authors expect that, in the Latvian context, the most suitable option will be a lower-capacity and more widely deployable solution, driven by the constraints faced by DH operators in technology choice.

Keywords – Decarbonize heat; district heating; electric boilers; heat pumps; MCDM; power-to-heat; SDG 13; socioeconomic; sociotechnical



Methodological framework for the assessment of DH electrification alternatives using TOPSIS-AHP and MULTIMOORA

ACKNOWLEDGEMENT

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CHALLENGES IN IMPROVING THERMAL COMFORT IN TENTS

Arturs PALCIKOVSKIS[1*], Ilja BORODINCES[2], Anna PETERMANE[3]

[1] *Riga Technical University, Ķīpsalas iela 6a, Riga, LV-1048, Latvia*
[2] *Rix Dimensija LTD, Ilūkstes iela 34, Riga, LV-1082, Latvia*
[3] *Riga State Gymnasium No. 1, Raiņa bulvāris 8, Riga, LV-1050, Latvia*
[*] ***Corresponding author.*** *Email address: arturs.palcikovskis@rtu.lv*

Abstract – This study investigates the opportunity of using phase change materials (PCMs) to enhance thermal comfort in temporary accommodations, with a focus on tent-based shelters. Tent-type shelters have long been widely used and remain in extensive use due to their established practicality and continued relevance across diverse applications. The research is motivated by the growing global demand for rapidly deployable housing solutions in situations where access to centralized energy infrastructure is limited or absent. Such contexts include humanitarian relief operations for populations displaced by armed conflicts and natural disasters, operational environments for military personnel, and leisure activities such as summer camps located in remote natural areas. To evaluate the practical potential of PCM-based thermal regulation, a series of controlled experiments was conducted in climate chamber using a tent equipped with a self-made thermal energy storage system. The system was designed to store excess heat when ambient temperatures are elevated and to release the stored energy as temperatures decrease, thereby moderating indoor temperature fluctuations. The experiment setup was equipped with sensors to measure indoor and outdoor temperatures, PCM temperature, and indoor thermal comfort, including a globe thermometer and a draught sensor. The experimental approach enables an assessment of how PCM integration can influence indoor thermal conditions within lightweight and low thermal mass shelters. The findings of this work are intended to contribute to the development of low-energy or passive thermal comfort solutions for temporary shelters, where conventional heating and cooling technologies may be impractical due to logistical constraints, fuel scarcity, or operational requirements. By focusing on a tent as a representative temporary accommodation, the study provides a relevant foundation for future optimization of PCM system selection, its design, and deployment strategies for off-grid temporary housing.

Keywords – Passive thermal regulation; phase change materials; temporary accommodation; thermal energy storage

Experimental test chamber and internal measurement setup

ACKNOWLEDGEMENT

The work was developed within the framework of the EU ERDF-funded project "RTU Doctoral Grants for Supporting Scientific Excellence in Smart Specialization Areas" (No. 1.1.1.8/1/24/I/007) within the framework of a doctoral grant (ID 8006).

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DISTRICT HEATING ELECTRIFICATION USING DECENTRALIZED HEAT PUMPS

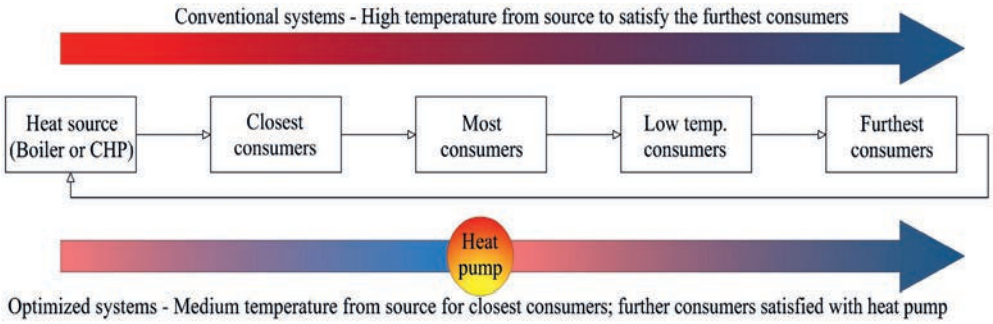
Lauris RITENBERGS-BALODIS[1*], Haralds SIKTARS[2], Vladimirs KIRSANOVS[3], Ivars VEIDENBERGS[4]

[1–4] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia*

[*] ***Corresponding author.*** *Email address: haralds.siktars@rtu.lv*

Abstract – In context of energy sector development into more decentralized manner, more attention is being focused on optimization of existing energy distribution networks. One solution, which is being increasingly researched is energy hubs, which produce, distribute and store multiple energy types, including heating. District heating for many moderate climate zone cities is essential during heating season, as well as the heat utilization from cogeneration plants, thus minimizing energy waste. Energy hubs benefit from locally produced energy over centralized approaches, which induce transmission losses in case of electricity. Similar approach is considered for district heating, replacing the high temperature heating to low-temperature heating, by installing heat pumps, since increased temperatures and distances increases the losses, thus reducing the efficiency of the system. Therefore, non-conventional solutions are modelled for a case study of small city in Latvia. Modelling is conducted in optimization model of TIMES, which is being provided with real data based on 3D physical modelling of losses and heat demands based on historical data. Physical calculations will be based on real master plan of the renovation project in said city. TIMES model is scenario-based tool; thus, it will provide most optimal result of the provided options, which include current system and its modifications with heat pumps in different locations in system. Scenarios will be evaluated by their economic and ecologic parameters, especially operational costs, GHG emissions and heating losses. Hypothesis is that current centralized biomass-based heating system can be optimized with heat pumps, thus reducing losses as well as operational costs. Based on this research results, overall energy hub modelling will be based on the same city, including electricity and other demands from consumers, as well as solar and wind energy production.

Keywords – Decentralized energy system; Energy Hub; heat loss; low temperature heating; sustainable community; TIMES model; optimization



District heating conceptual scheme with conventional solutions and optimized system concept

ACKNOWLEDGEMENT

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DECARBONISATION OF DISTRICT HEATING – REVIEW OF CURRENT SYSTEM DYNAMICS MODELLING APPROACHES

Ilze Katrīna LUMPOVA[1*], Madara RIEKSTA[2], Gatis BAZBAUERS[3]

[1–3] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia*

[2] *JSC Rigas Siltums, Cēsu iela 3A, LV-1012, Latvia*

[*] ***Corresponding author**. Email address: ilze-katrina.lumpova@edu.rtu.lv*

Abstract – Decarbonization of the heating sector, with an emphasis on expanding and decarbonizing District Heating (DH), is critical for achieving national and EU-level decarbonization goals. However, decarbonization of DH presents a set of conflicting goals, also referred to as the "energy trilemma" – ensuring sustainability, system security and reliability, and economic viability. To achieve successful decarbonization of DH, all three goals need to be optimally balanced. System Dynamics (SD) modelling allows the observation of complex system behaviour over time by observing feedback loops and dependencies within a given system. Thus, given the complexity of DH systems and their interdependence with other energy systems, an SD modelling approach is widely used to model different aspects of the future development of DH, as well as to observe the dynamic effects and feedback loops emerging from technology integration and policy interventions. This paper develops a systemic literature review approach to analyse and review existing studies that employ SD modelling of DH systems. It identifies the scope and aim of the models and summarizes the main feedback loops identified and key takeaways, evaluating to what extent the energy trilemma is currently explored in existing literature. It is found that existing studies predominantly focus on modelling the integration of specific technologies into DH systems, thus covering technological aspects of DH decarbonization. However, studies covering systemic analysis of economic viability, system security, and environmental impacts of DH decarbonization remain fragmented, as the aspects are mostly explored separately. As a result, current research offers only a partial understanding of how the conflicting goals of the energy trilemma interact through feedback loops and create interdependencies within DH systems.

Keywords – Decarbonisation; district heating; energy trilemma; system dynamics

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HIGH ENERGY EFFICIENCY MICRO-JET HEAT EXCHANGER

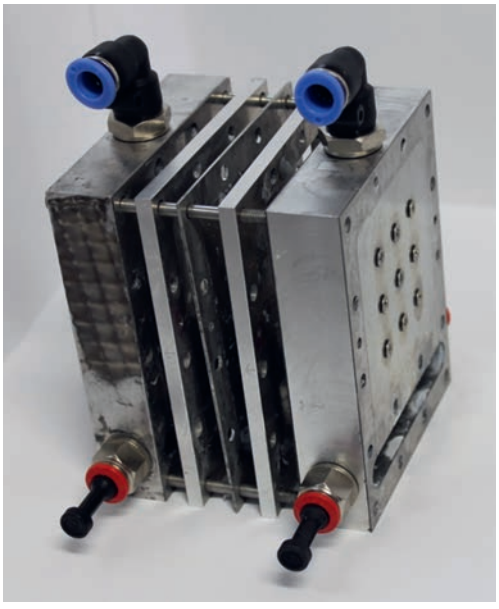
Artur RUSOWICZ*

Warsaw University of Technology, 00-661 Warsaw, Pl. Politechniki 1, Poland

* ***Corresponding author.*** *Email address: artur.rusowicz@pw.edu.pl*

Abstract – The purpose of the present study is an experimental investigation of microjet array heat exchanger performance. Impinging jet cooling technique has various advantages such as one of the highest known single phase heat transfer coefficients, high heat flux removal rates with small surface-to-coolant temperature differential, possibility of its regulation, and direct contact with the cooling surface. Jet impingement is widely used in industrial applications for drying paper and textiles, quenching metals, turbine blade cooling, and is described as one of cooling methods, that can meet increasing requirements of electronic devices. In the experimental part, heat exchanger, instrumentation and method were described. Heat exchanger with four diaphragms with 364 inline round orifices of diameter 160μm, ratio of jet area to heater area Ar = 0.0019 and ratio between jet-to-jet spacing and their diameter s/d = 19 was used. Water was used as the investigated fluid. Volumetric flow rate was changed manually in the rage of 12.8 ÷ 133.3 mL/s which corresponds to Reynolds number values in the range of 145 ÷ 2275. Liquid water jet impingement cooling was investigated experimentally in four different configurations – standoff between nozzle exit and heat exchange surface was changed by spacers of thickness 1, 3, 5 and 7 mm. Experimental results were used in calculation of experimental heat transfer coefficient k_{exp}. Experimentally determined coefficients of this investigation were compared with values predicted by three different correlations given by Meola, Robinson and Schnitzler and Womac. Results of present experimental investigation may be used to establish optimal parameters for this type of heat exchangers, and provide relevant information about their performance.

Keywords – Experimental research; heat transfer



Micro-jet Heat Exchanger

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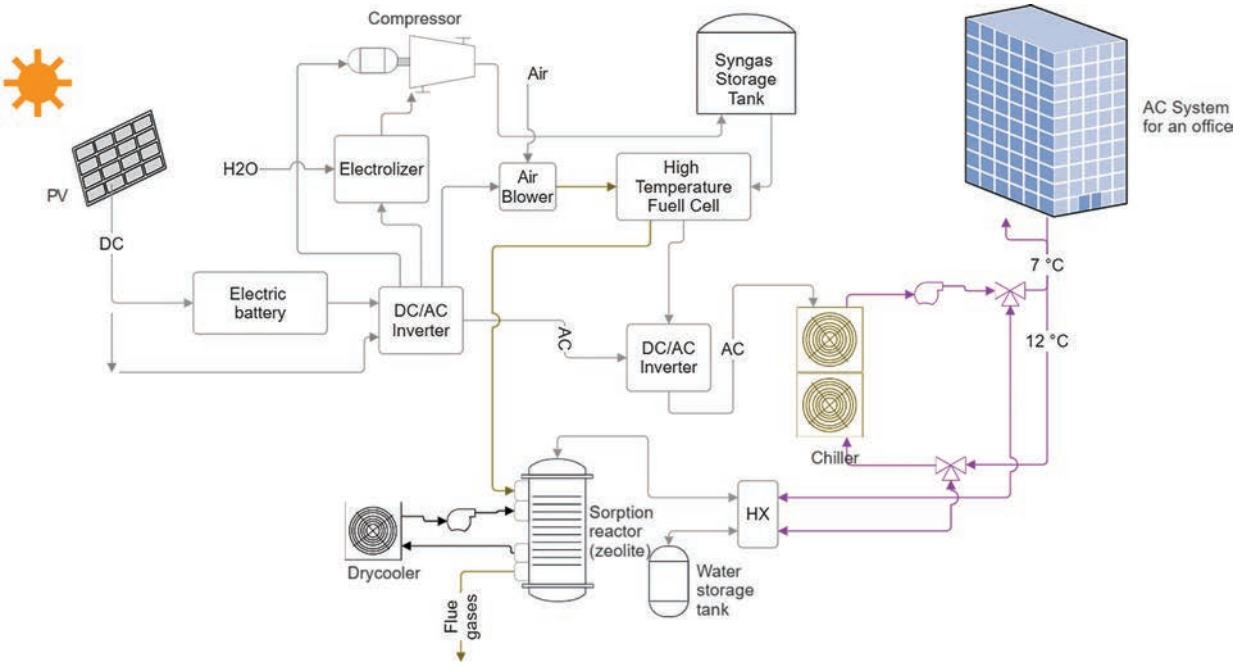
HIGH-TEMPERATURE FUEL CELL HEAT UTILIZATION FOR COLD STORAGE IN AIR CONDITIONING SYSTEM

Andrzej GRZEBIELEC[1*], Katarzyna KATANA[2], Karolina MAJEWSKA[3], Marcin BŁESZNOWSKI[4], Artur RUSOWICZ[5]

[1–4] *Warsaw University of Technology, pl. Politechniki 1, 00-661 Warsaw, Poland*
[5] *Institute of Power Engineering - National Research Institute, 8 Mory St. 01-330 Warsaw, Poland*
[*] ***Corresponding author**. Email address: andrzej.grzebielec@pw.edu.pl*

Abstract – During the day, temperatures rise causing a gap between air conditioning systems demand and energy availability. Renewable energy sources such as photovoltaic cells are a promising option for powering these systems. However, due to the thermal inertia of buildings, there still occurs a temporal misalignment between peak cooling demand and energy supply, highlighting the need for efficient energy storage systems. This study investigates advanced strategies for integrating high-temperature fuel cells (HTFC) into air conditioning systems, with a focus on cold storage applications. Two main approaches are analysed. The first involves storing electrical energy by producing hydrogen or syngas through electrolysis, converting it in HTFCs, and using the generated electricity and heat to power chillers. The second approach explores storing cold in a zeolite sorption reactor, which utilizes waste heat from the fuel cells. The study analyses the influence of storage parameters, including working gas volume and sorbent bed size on overall system efficiency, responsiveness to dynamically changing cooling demand, as well as the applicability in a humid continental climate (Warsaw, Poland). Hybrid approaches that combine electrical energy storage with sorption-based cold storage may offer superior performance by balancing peak demand coverage with renewable energy availability. The findings provide insights into the design of renewable energy-powered air conditioning systems that utilize HTFCs, contributing to the development of sustainable cooling technologies.

Keywords – Electrolysis; sorption reactor; syngas; thermal energy storage; zeolites



Schematic of a Renewable Energy-Powered Air Conditioning System with High-Temperature Fuel Cells and Sorption-Based Cold Storage

ACKNOWLEDGEMENT

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DESIGN AND OPTIMIZATION OF OFF-GRID HYBRID ENERGY SYSTEM FOR SMALL ISLANDS

Mohd Basit WANI[1], Sreenath SUKUMARAN[2*], Anna Volkova[3], Azlin Mohd Azmi[4]

[1–3] *Department of Energy Technology, Tallinn University of Technology, Tallinn, 19086, Estonia*
[4] *Solar Research Institute, Universiti Teknologi MARA, Shah Alam, 40450, Malaysia*
[4] *School of Mechanical Engineering, College of Engineering, Universiti Teknologi MARA, Shah Alam, 40450, Malaysia*
[*] ***Corresponding author**. E-mail: sreenath.sukumaran@taltech.ee*

Abstract – Small islands are at the forefront of just energy transition. While their closed environment supports low energy footprint, there are several challenges related to achieving a high renewable fraction without resorting to component oversizing or energy curtailment. This study aims to design and simulate a hybrid energy system for meeting energy demands of a small island in Estonia. At first, an off-grid renewable microgrid concept is conceived as the case study for Vormsi island. The electrical and thermal load for the proposed microgrid is obtained from publicly available databases. Photovoltaic (PV) and wind power systems were taken as the source for the electrical demand. The thermal load is represented through a thermal load controller that converts surplus renewable electricity into useful heat. A natural gas boiler and battery storage are integrated into microgrid to mitigate the intermittency of renewable electricity. Secondly, HOMER Pro software is used to identify the optimal system design by minimizing the net present cost while meeting reliability constraints such as zero annual capacity shortage and operating reserve requirements. It also evaluates the feasibility of the sizing combinations that involve trade-offs between generation, storage, and conversion capacities. It was observed that a PV-dominant microgrid solution can deliver the required energy loads. Battery storage on the order of tens of megawatt-hours provided multi-hour energy autonomy, keeping the renewable fraction close to 98 percent. The annual operating cost for the optimal configuration is estimated to be approximately USD 660 000. The results showed that integrating wind generation can mitigate PV oversizing and improve cost benefits compared to PV-only configurations. The simultaneous operation of electric–thermal loads increased renewable energy utilization, effectively minimizing fuel consumption of backup boilers. This study provide insights for policymakers and island municipalities that are pursuing reliable, clean, and affordable energy solutions, especially in the Baltic Sea Region.

Keywords – HOMER Pro; hybrid systems; off-grid microgrid; small islands; techno-economic analysis

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SYSTEMATIC SYNTHESIS OF TECHNICAL TOOLS FOR STRENGTHENING REGIONAL ENERGY TRANSITIONS

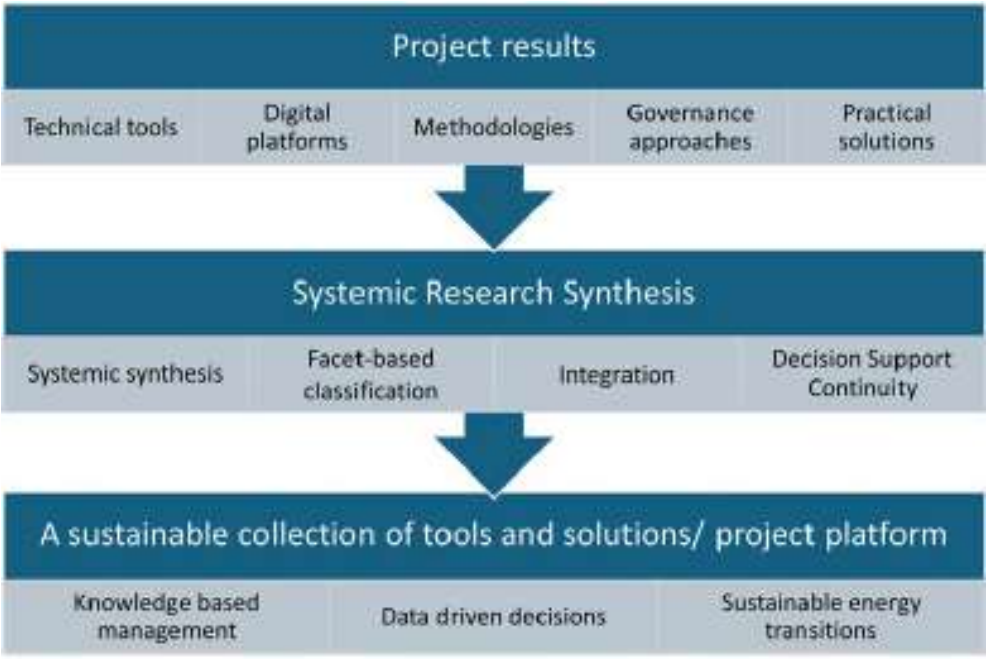
Kristiana JASUREVICA[1], Zane PIPKALEJA[2*], Dace LAUKA[3], Veronika LIBEROVA[4], Jelena PUBULE[5], Aiga BARISA[6]

[1–6] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Rīga, LV1048, Latvia*

[*] ***Corresponding author.*** *Email address: zane.pipkaleja@edu.rtu.lv*

Abstract – The transition of the energy sector to a climate-neutral, resource-efficient and sustainable development model is one of the central priorities of the European Union's policy documents and funding programmes. In recent years, increasing support has been provided to projects that address complex and multi-level challenges in the field of regional and local energy transition, developing technical tools, digital platforms, methodologies, governance approaches and practical solutions for public institutions and other stakeholders. These projects create significant added value in the form of knowledge, innovation and practical tools. However, at the same time, there is a significant problem - the fragmentation of project results. The developed tools and solutions are often scattered across different projects, platforms and publications, without a unified structure and interconnection. After the end of the project life cycle, access to project results becomes limited, their use decreases, and knowledge transfer to other territories and institutions is not fully ensured. Consequently, the overall investment effect and practical impact on achieving the goals of the energy transition also decrease. The study used a combined methodological approach, combining a systematic synthesis of project results with a facet-based classification. A structured analysis of technical tools, methods and solutions was carried out, identifying their areas of application, mutual connections and overlaps. This approach allowed to identify the most significant gaps in the regional energy transition, to assess the interaction and synergy potential of the developed tools, as well as to create a structured basis for an integrated combination of tools and knowledge. The results of the analysis, also based on stakeholders' opinions and practical needs, allowed us to determine that the main challenge is not the availability of individual tools, but their mutual integrity, complementarity and applicability within a unified energy transition management framework. The results highlight shortcomings in integration, decision support continuity and cross-sector coordination. At the same time, the study shows that a systematic, facet-based synthesis of project results creates the basis for a sustainable collection of tools and solutions – a unified project platform or Resource Hub – that allows for the structured use of existing technical resources, strengthening data-based decision-making and building a knowledge-based approach to regional energy transition management.

Keywords – Capacity building; facet-based criteria; knowledge transfer; resource hub; solution mapping; transnational knowledge



The methodology of synthesizing the technical tools

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USE OF WASTE HEAT FROM A WASTEWATER TREATMENT PLANT IN A DISTRICT HEATING NETWORK: A CASE STUDY FROM LATVIA

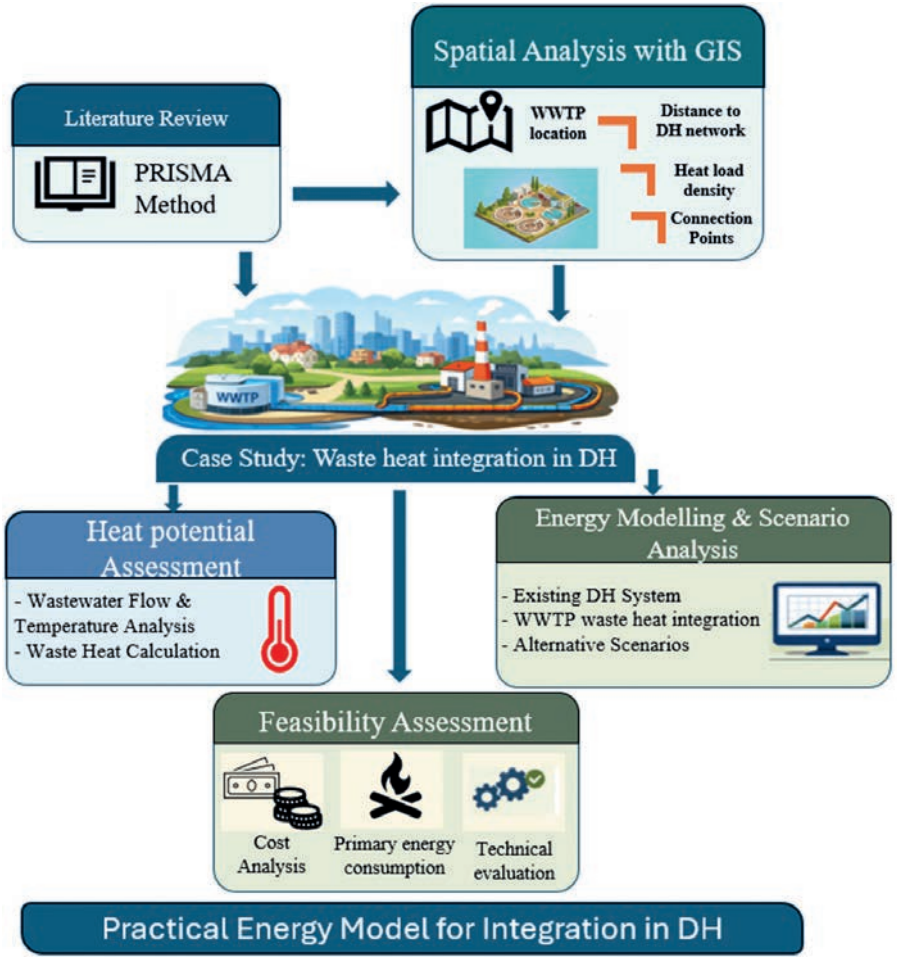
Marita Agate ZIRNE[1*], Vivita PRIEDNIECE[2]

[1,2] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, LV-1048, Riga, Latvia*

[*] ***Corresponding author.*** *Email address: marita-agate.zirne@edu.rtu.lv*

Abstract – Increasing the share of renewable energy sources (RES), reducing greenhouse gas (GHG) emissions, and improving energy efficiency in district heating (DH) systems are not only technical challenges, but also essential steps towards a sustainable and climate-neutral future, helping the European Union (EU) to achieve its clean energy and climate goals. This step is closely related to the EU energy policy, which promotes energy efficiency implementation in DH and cooling systems. For over 100 years, DH systems have proven to be an effective way to supply heat to buildings, and the development of DH has enabled the use of multiple heat sources, including low-temperature sources such as waste heat. In Latvia, similarly to other Nordic Countries and the Baltic States, heating accounts for a large part of energy consumption, and DH plays a crucial role in the heat supply structure. However, many of these systems are outdated and dependent on fossil fuels, which is why their sustainability and energy efficiency are limited. To ensure that DH systems comply with the EU goals, modernization is needed, including the integration of RES, the deployment of zero-emission technologies, and improvements in energy efficiency. In this study, the PRISMA method is used for literature analysis to evaluate the available research on the use of waste heat in DH systems. To develop an energy model for the case study on integrating waste heat from a wastewater treatment plant (WWTP), a multi-level methodology combining spatial analysis, energy demand assessment, and feasibility analysis is applied. A geographic information system (GIS) is used for spatial analysis to identify the location of WWTPs, their distance to the existing DH network, the density of heat loads in the surrounding area, and potential connection points to the DH. The potential amount of recoverable heat from WWTP is determined through an annual analysis of wastewater flow and temperature data, using a standardized method for heat calculation. The energy model is based on a detailed deterministic simulation of the heat supply system, representing both the existing DH system and several alternative scenarios that incorporate waste heat recovery from WWTPs, including the use of heat pumps. These scenarios are evaluated in terms of their impact on primary energy consumption and peak load. This methodological approach enables the development of a practically applicable case study model, which can serve as a foundation for the broader integration of WWTP waste heat into DH systems in Latvia.

Keywords – District heating; energy modelling; sustainability; waste heat



Research framework for the DH system and waste heat

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MODELLING AND ENERGY EFFICIENCY IMPROVEMENT IN CHEMICAL BATCH OPERATIONS USING DATA-DRIVEN SYSTEM IDENTIFICATION

Gerald STEINMAURER[1], Helmut MUEHLEDER[2]

[1,2] *University of Applied Sciences Upper Austria, Research group ASIC, Stelzhamerstraße 23, Wels*
[*] ***Corresponding author.*** *Email address: gerald.steinmaurer@fh-wels.at*

Abstract – Chemical batch processes generate large amounts of measurement data, making it difficult to identify which variables are most important for understanding and improving energy use. As energy efficiency becomes increasingly relevant for both cost and sustainability, it is essential to analyze power demand in a systematic way. This paper presents a practical, data driven approach for studying a complex chemical process with the goal of understanding and predicting the power consumption during different operating stages. The contribution begins by examining all available process data, which includes many measurement channels describing temperatures, rotational speed, height level and other process behaviors. Since working with too many variables can be inefficient and may hide important effects, a correlation analysis is carried out first. This step helps to remove redundant or non informative signals and allows the focus to remain on the variables that have the strongest influence on energy consumption. Reducing the number of variables improves the clarity of the analysis and provides a good basis for building reliable models. After selecting the most relevant measurements, the power demand of several key process steps is investigated. These steps represent typical phases of the batch process, especially heating and mixing. The power consumption within each phase is analyzed with respect to important input variables: product temperature, agitator rotational speed, and container filling level. This analysis shows how different operating conditions influence energy demand, for example how viscosity changes affect agitator load or how temperature gradients impact heating requirements. These findings are essential for building accurate models that reflect real process behavior. Using the most important variables, a system identification procedure is then applied to model the dynamic relationship between the selected inputs and the observed power demand. Three model structures are tested and compared: ARX (Auto Regressive with eXogenous input), OE (Output Error), and ARMAX (Auto Regressive Moving Average with eXogenous input). Each model type captures different aspects of the process dynamics, including delays, disturbances, and deterministic trends. The identification process includes parameter estimation, validation, and evaluation based on prediction accuracy. From the best performing models, continuous time transfer functions are derived. These transfer functions describe how the power demand responds to changes in the chosen process variables and allow simulations of energy consumption under a wide range of operating scenarios. This provides a useful tool for optimization, process design, and potential improvements in control strategies. Overall, the paper shows that combining correlation based variable reduction, targeted power-demand analysis, and advanced system identification methods offers an effective approach for understanding the energy behavior of complex chemical batch processes. The resulting models support more efficient and sustainable operation by enabling improved predictions and optimization of power consumption.

Keywords – Chemical process; energy consumption; power demand analysis; system identification

ACKNOWLEDGEMENT

This work was supported by the government of Upper Austria and FFG in the project "Indekmet [Research grant FFG-Nr. FO999920762" and "COMPESTO – comprehensive energy storage" [Research grant Wi-2022-600132/7-Au].

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REDUCING BILLING GAP IN ENERGY COMMUNITIES VIA FORECAST-BASED SHARING COEFFICIENTS

Javier SERRANO GONZÁLEZ[1*], Joan Tomàs VILLALONGA PALOU[2], Jesús Manuel RIQUELME SANTOS[3], Juan Manuel ROLDÁN FERNÁNDEZ[4]

[1–4] *Department of Electrical Engineering, University of Seville Seville, Spain*

[*] ***Corresponding author.*** *Email address: javierserrano@us.es*

Abstract – Collective self-consumption (CSC) and energy communities increasingly rely on dynamic sharing coefficients to allocate photovoltaic (PV) generation among participants. In several regulatory settings, these coefficients must be communicated in advance (e.g., one month ahead) and may vary hour by hour. This creates a practical challenge: allocation ratios must be computed ex ante, while actual individual loads are only known ex post. Consequently, community-level costs and perceived fairness can become strongly dependent on the accuracy of month-ahead, hour-by-hour demand forecasts, particularly in residential settings where only historical smart-meter data are available. This paper proposes a transparent forecasting-and-allocation framework to compute regulation-compliant hourly sharing coefficients under a strict no-look-ahead protocol. The method follows a two-step approach. First, each participant's hourly consumption for the forthcoming month is predicted using simple, interpretable persistence-type models capturing complementary patterns: previous-month hour-of-day profiles (PM), the same calendar month in the previous year (PY), rolling multi-month hour-of-day profiles (ROLL), and a weekly seasonal profile (SP). Second, forecasts are combined through an ensemble (ENS) that learns hour-of-day–specific weights from recent forecast errors via inverse-variance weighting, enforcing a sum-to-one constraint. The resulting individual forecasts are normalized across participants at each hour to obtain the dynamic sharing coefficients, which are then applied ex ante to allocate PV generation during the subsequent month. The framework is evaluated in a realistic CSC case study with 15 residential customers under Spain's regulated PVPC 2.0TD tariff, using hourly demand from real smart-meter data and PV production from PVGIS for a 25 kW plant in Seville (Spain). Performance is assessed through the annual "gap to baseline", defined as the relative excess annual bill with respect to a perfect-information benchmark based on ex post optimal allocation (used only as a reference). Results show that the ensemble achieves the smallest excess cost among practical methods, at approximately +5.3 % above the baseline. Alternative practical predictors exhibit larger gaps, ranging from about +6.1 % (SP) to +10.7 % (PY), with intermediate values of ∼+8.4 % (ROLL) and ∼+9.0 % (PM). In terms of gap reduction, ENS decreases the excess cost by roughly ∼12 % versus SP, ∼36 % versus ROLL, ∼40 % versus PM, and ∼50 % versus PY.

Keywords – Collective self-consumption; dynamic sharing coefficients; electricity demand forecasting; forecasting ensemble; renewable energy regulation; seasonal decomposition

ACKNOWLEDGEMENT

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RESILIENCE OF CRITICAL ENERGY INFRASTRUCTURE: A MULTI-CRITERIA ASSESSMENT OF THE ŽILINA HEATING PLANT

Michal MIŠKE[1*], Maksims FEOFILOVS[2], Francesco Romagnoli[3], Zdeněk DVOŘÁK[4]

[1,4] *Faculty of Security Engineering, University of Žilina, Univerzitná 8215, 010 26, Žilina, Slovakia*
[2,3] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia*
[*] ***Corresponding author.*** *Email address: michal.miske@uniza.sk*

Abstract – This case study, developed within the APRIORI project, focuses on assessing the resilience of a district heating system as a key element of national critical energy infrastructure. The object under analysis is the Žilina Heating Plant, one of the largest district heating facilities in Slovakia, supplying heat and electricity to approximately 20 000 households and essential public institutions. The study examines the resilience of district heating systems considering technical, organizational, environmental, and security perspectives, with particular emphasis on risk identification and threat assessment. Identified threats include technological failures, fire hazards, environmental impacts, cyber threats, and intentional attacks, as well as long-term challenges such as infrastructure ageing and dependence on fossil fuels. A structured multi-criteria decision-making approach, using TOPSIS, was applied to evaluate the severity and priority of the identified risks. The criteria reflected key dimensions of district heating resilience, including probability of occurrence, repair costs, transmission and supply losses, restoration time, and impact intensity. The results confirm that the Žilina district heating system is a critical element of regional infrastructure, whose continuous operation is essential for energy security, public safety, and social stability. While the system benefits from experienced personnel, established emergency cooperation, and partial technological modernization, vulnerabilities remain in areas such as fuel dependency, automation level, and environmental burden. The case study demonstrates that resilience enhancement in district heating systems can be effectively achieved through a combination of traditional preventive measures and advanced technologies, including automation, digital monitoring, predictive maintenance, and cybersecurity protection. The findings contribute to the validation of the APRIORI resilience assessment methodology and provide practical recommendations applicable to district heating systems in other European regions.

Keywords – Critical Infrastructure resilience; district heating; energy security; multi criteria analysis; resilience assessment; risk analysis

ACKNOWLEDGEMENT

The work has been supported by the following project: “Advanced Technologies for Physical ResIlience Of cRitical Infrastructures (APRIORI)”, code: SPS G6140, funded by the NATO, Science for Peace and Security (SPS) Call for Proposals 2023-1.

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ENERGY LABEL IMPROVEMENT THROUGH RCOP-BASED HEATING OPTIMIZATION IN HEAT PUMP BUILDINGS

Heino PIHLAP[1*], Allan TOOMING[2], Helar NIILO[3], Heiki LILL[4], Marten MADISSOO[5]

[1–5] *Institute of Forestry and Engineering, Estonian University of Life Sciences, Fr. R. Kreutzwaldi 56, Tartu, Estonia*

[*] ***Corresponding author.*** *Email address: Heino.pihlap@emu.ee*

Abstract – The growing usage of renewable energy sources in building energy systems has consequently increased the need for advanced control strategies that simultaneously enhance system efficiency and improve performance within regulatory assessment frameworks. In particular, heat pump–based heating systems must be evaluated not only by their operational efficiency but also by their contribution to renewable energy utilization as reflected in European Union (EU) building energy label calculations. This study examines the effect of RCOP (renewable coefficient of performance)-based heating optimization on the EU energy performance classification of a renewable energy-assisted heat pump building. The proposed optimization approach prioritizes heat pump operation during periods of high on-site renewable energy availability, with the objective of minimizing grid electricity consumption whilst maintaining indoor thermal comfort. A detailed simulation-based analysis is conducted using a representative building model equipped with a heat pump and a renewable energy generating source (e.g. PV panels). The performance of the RCOP-based control strategy is compared against a conventional reference control strategy, following standardized EU energy label calculation methodology. The results demonstrate that RCOP-based optimization leads to notable reduction in grid electricity demand as well as an increase in renewable energy self-consumption. These operational improvements translate into a more favorable outcome in EU energy label calculation, resulting in an improved energy performance classification for the building. The findings indicate that conventional control strategies may underestimate the renewable contribution of heat pump systems, whereas RCOP-based control more accurately aligns system operation with regulatory performance metrics. The study concludes that integrating RCOP-based heating optimization into heat pump control design can significantly enhance both energy system sustainability and compliance with EU energy efficiency frameworks. It is recommended that future building energy assessments and control strategies incorporate RCOP-oriented indicators to better reflect renewable energy utilization and support policy-driven decarbonization goals in the building sector.

Keywords – Energy self-consumption; grid electricity reduction; heat pump operation; sustainable control strategies

https://doi.org/10.7250/CONECT.2026.024

IMPACT OF BUILDING USAGE REGIME ON THE RESIDENTIAL ENERGY LABEL OF HEAT PUMP-HEATED BUILDINGS

Heino PIHLAP[1*], Allan TOOMING[2], Helar NIILO[3], Heiki LILL[4], Marten MADISSOO[5]

[1–5] *Institute of Forestry and Engineering, Estonian University of Life Sciences, Fr. R. Kreutzwaldi 56, Tartu, Estonia*

[*] ***Corresponding author.*** *Email address: Heino.pihlap@emu.ee*

Abstract – The current study investigates the influence of building usage regimes on the residential energy performance label of buildings heated by heat pump systems. While energy labels are commonly perceived as indicators of a building's technical quality, this research emphasizes the significant role of occupant-related factors in determining final energy classification outcomes. The analysis focuses specifically on consumer-side variables, including the number of occupants, duration of daily occupancy, lifestyle characteristics, and energy consumption behavior, and evaluates how these parameters affect overall energy use and the resulting energy label. Different household usage regimes are examined to illustrate variations in residential energy demand under otherwise identical technical conditions. Case scenarios include pensioner households, where occupants typically remain at home for longer periods and maintain higher indoor comfort temperatures, as well as families with children, whose energy use patterns are shaped by irregular schedules, increased domestic hot water demand, and higher electricity consumption for household appliances. By comparing these distinct usage profiles, the study quantifies the extent to which occupant behavior alone can influence building energy performance indicators. The results demonstrate that buildings with the same construction quality, thermal envelope characteristics, and heating system efficiency may receive different energy label classifications solely due to differences in user behavior and occupancy patterns. This finding highlights a critical limitation of current residential energy labeling systems, which rely primarily on measured or calculated energy consumption values without adequately accounting for behavioral variability. In heat pump-heated buildings, the amount of electrical energy required for space heating and domestic hot water production is strongly dependent on the availability of latent energy from the surrounding environment, which in turn affects the proportion of electricity drawn from the grid. User-driven demand fluctuations therefore directly impact system performance and annual energy consumption figures. These findings underline the importance of incorporating usage-related parameters when interpreting residential energy labels, particularly in financial and regulatory contexts. Energy labels are increasingly used in mortgage approvals, bank loan assessments, and real estate valuation processes, where they may influence financial decisions and perceived investment risks. Without acknowledging the role of occupant behavior, energy labels may not accurately reflect the intrinsic energy efficiency of a building. Consequently, a more nuanced interpretation framework is required to ensure fair and technically sound evaluations of residential energy performance.

Keywords – Consumer-side impact; energy consumption patterns; electricity grid demand; latent energy; occupancy patterns

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SECOND LIFE FOR EV BATTERIES: UNLOCKING ESTONIA'S ENERGY STORAGE POTENTIAL

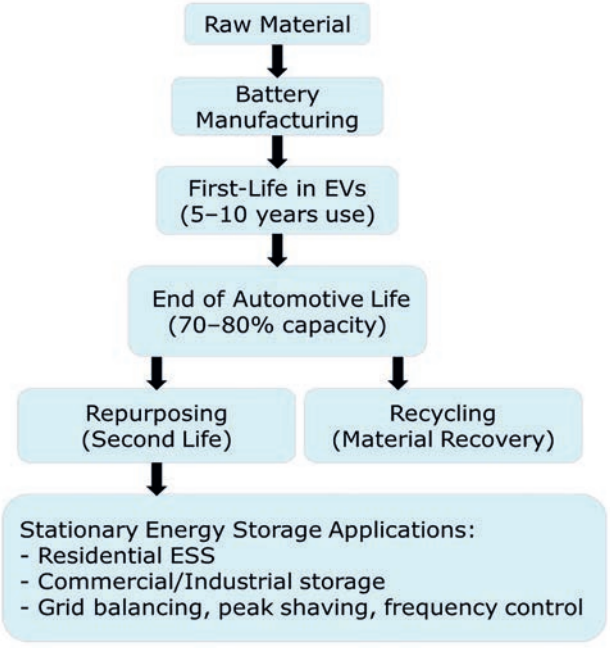
Noman SHABBIR[1*], Jelizaveta KRENJOVA-CEPILOVA[2]

[1,2] *FinEst Centre for Smart Cities, Tallinn University of Technology, Estonia.*

[*] ***Corresponding author.*** *E-mail address: noman.shabbir@taltech.ee*

Abstract – The rapid expansion of electric vehicles (EVs) in Europe is generating growing volumes of batteries reaching the end of their automotive life. Repurposing these batteries for stationary energy storage is promoted as a key strategy for advancing battery circularity and supporting renewable energy integration. Yet the deployment of second-life EV batteries remains limited and uneven, particularly in small markets with low EV penetration. This paper examines the policy and institutional barriers shaping second-life battery adoption in the Baltic region, with a primary focus on Estonia. Drawing on interviews with industry actors in Norway and Latvia, expert discussions, and a national stakeholder workshop involving safety authorities and regulators, the study shows that limited uptake is not driven by technological constraints or lack of interest, but by governance-related challenges. These include ambiguous battery classification, unclear liability and extended producer responsibility, weak safety supervision, lack of testing and certification capacity, and fire safety concerns that deter insurers. Comparative insights from Nordic and Baltic cases indicate that EU-level regulation alone is insufficient to enable second-life markets. Instead, targeted national measures addressing safety governance, liability, and institutional capacity are required. The findings highlight the importance of meso-level policy implementation for advancing battery circularity in emerging energy markets.

Keywords – Battery repurposing; circular economy; electric vehicle; Energy Storage Systems (ESS); second-life batteries



Lifecycle of EV Batteries and Second-Life Pathways.

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TOWARDS CARBON LIMIT VALUES FOR BUILDINGS IN LATVIA: A LIFE-CYCLE PERSPECTIVE

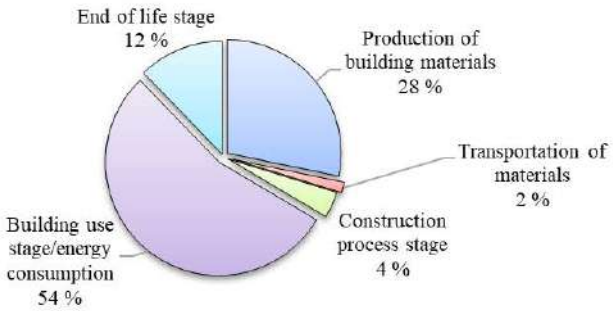
Lauma AUERMANE[1*], Maksims FEOFILOVS[2], Agris KAMENDERS[3]

[1–3] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia*

[*] ***Corresponding author.*** *E-mail address: agris.kamenders@rtu.lv*

Abstract – The energy sector accounts for more than three quarters of the European Union's (EU) greenhouse gas emissions. Heating and cooling of buildings consume 40 % of the total EU energy demand, while 75 % of EU buildings are still not energy efficient; therefore, the decarbonization of this sector is essential for achieving climate targets by 2050. European Parliament and Council (2024) Directive (EU) 2024/1275 on the energy performance of buildings the focus of building decarbonization has expanded beyond operational energy performance towards a whole-life carbon approach. In this light, the study analyses the characteristics of the Latvian and EU building sectors and evaluates the regulatory framework for decarbonization targets and their implementation scenarios. A comparative analysis of CO_2 limit values in the Nordic countries and Latvia is carried out based on building life cycle stages. The results show that in several EU Member States, CO_2 limit values have already been established for specific stages of a building's life cycle, whereas such regulation has not yet been introduced in Latvia. Considering the specifics of the Latvian construction sector, the analysis confirms the need to implement a unified methodology and to gradually introduce CO_2 limit values. In light of the EU Green Deal and the established decarbonization targets, the results highlight the urgent need to reduce building emissions by optimizing both operational energy use and related emissions, as well as emissions generated during the product and construction stages (A1–A5). The study seeks to assess the extent to which Latvia's nearly zero-energy building (NZEB) requirements align with the CO_2 threshold frameworks applied or planned in the Nordic region, and to propose potential solutions for improving performance indicators. The main objectives of the study are: i) To compare the NZEB requirements for new buildings in Latvia with the established and forthcoming CO_2 threshold requirements and zero-emission building definitions in the Nordic countries; ii) To propose CO_2 threshold levels for new buildings in Latvia and to develop a zero-emission building definition adapted to Latvian conditions.

Keywords – Building decarbonization; CO_2 limit values; Life Cycle Analysis (LCA); sustainable buildings



Share of carbon emissions by life-cycle stage for a residential building complex in Riga

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MODELLING THE ECONOMIC VIABILITY OF AGGREGATED BUILDING RETROFITS IN CARBON MARKETS

Siti Shahada SHAMSHUDDIN[1], Ashwin THURAIRAJAH[2], Azlin MOHD AZMI[3*]

[1,3] *Faculty of Mechanical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia*
[2] *GreenRE Sdn Bhd, Wisma REHDA, 47301 Petaling Jaya, Selangor, Malaysia*
[*] ***Corresponding author.*** *E-mail address: azlinazmi@uitm.edu.my*

Abstract – Building energy efficiency retrofits are a critical component of long-term energy transitions, yet their deployment at scale remains constrained by limited access to viable financing mechanisms. Carbon markets offer a potential revenue stream to support retrofit investments; however, individual building projects are often too small to absorb the high transaction, monitoring, and verification costs required for carbon credit issuance. This study develops a quantitative break-even modelling framework to assess the economic viability of building energy efficiency retrofits and to identify the conditions under which aggregation becomes necessary for market participation. Using empirical data from 11 GreenRE-certified commercial buildings in Malaysia, we estimate potential emission reductions associated with common retrofit measures. A cost-based model is constructed to estimate the total volume of verified carbon units (VCUs) required to recover project-related costs under alternative assumptions for carbon prices, verification frequencies, and crediting periods (7 and 10 years). The analysis evaluates the scale of emission reductions needed for cost recovery and uses this to infer the role of aggregation in enabling market entry. Results show that at a representative global voluntary carbon market price of USD 3 per tCO_2, individual building retrofit projects are economically unviable. Under optimized cost structures and biennial verification, break-even conditions require cumulative emission reductions in the range of approximately 40 000–200 000 tCO_2 over the studied crediting periods, indicating that aggregation across multiple buildings is essential. The model identifies a minimum carbon price threshold of at least USD 4 per tCO_2 for aggregated building retrofit projects to achieve economic viability. The findings highlight the importance of aggregation mechanisms, carbon price signals, and cost-efficient MRV designs in enabling building energy efficiency investments. This study provides policy-relevant insights for market designers and policymakers seeking to leverage carbon markets to support demand-side decarbonization in Malaysia and other emerging economies.

Keywords – Energy efficiency; emission reduction potential; measurement, reporting and verification (MRV); programmatic approaches; verified carbon unit (VCU); voluntary carbon market (VCM)

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IMPLEMENTATION OF BEHAVIOR CHANGE MEASURES FOR THE CIRCULAR ECONOMY IN HOUSEHOLDS

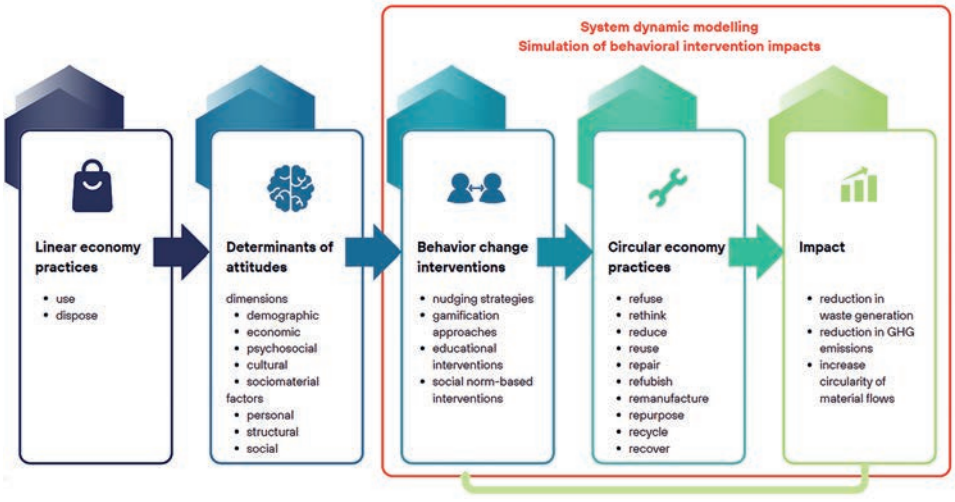
Rezija VARNA[1*], Inguna BREMANE[2], Ritvars FREIMANIS[3], Andra BLUMBERGA[4]

[1-4] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/K1, Riga, LV-1048, Latvia*

[*] ***Corresponding author.*** *E-mail address: rezija.varna@edu.rtu.lv*

Abstract – The circular economy is considered as a potential solution to the global environmental challenges of the 21st century, including climate change, resource scarcity, rising pollution, and related issues. However, the implementation of circular economy principles in households remains insufficient, largely due to limited awareness and engagement. Human behavior is influenced by many different factors and is often resistant to change. An integrated approach is necessary to change behavior patterns. The aim of this study is to assess the impact of behavioral interventions on household habits in relation to the implementation of circular economy principles. The study conducted a thematic literature review covering 98 published scientific articles on research related to the implementation of behavioral interventions to promote principles of the circular economy. Based on the results obtained, a system dynamics model was developed using Stella Architect to more effectively evaluate the types of interventions and their impact. The results show the impact of four main groups of interventions: (1) nudging strategies, (2) gamification approaches, (3) social norm –based interventions, and (4) education interventions, and their impact on changes in households. The developed model indicates that the interaction between different interventions significantly influences human behavior and can accelerate the transition towards the implementation of circular economy principles. However, further research is needed to better understand the sustainability of behavioral interventions and to identify the most effective approaches.

Keywords – Behavior change interventions; educational interventions; gamification approaches; nudging strategies; social norm-based interventions



Framework of behavior change interventions influencing the adoption of circular economy practices and their environmental impact

02

ENERGY AND ENVIRONMENTAL MODELLING

https://doi.org/10.7250/CONECT.2026.029

INTEGRATED OPTIMIZATION OF HYBRID ENERGY SOURCES FOR RESIDENTIAL BUILDINGS

Anatoliy PAVLENKO[1*], Dariusz MIKIELEWICZ[2]

[1] *Kielce University of Technology, al. Tysiąclecia Państwa Polskiego 7, 25-314 Kielce Poland*
[2] *Gdańsk University of Technology, al. Zwycięstwa 27 80-219 Gdańsk Poland*
[*] ***Corresponding author.** Email address: apavlenko@tu.kielce.pl*

Abstract – The optimization of hybrid building energy systems is commonly addressed using two main approaches: model-based and rule-based energy management strategies that ensure operational stability, and heuristic or algorithmic methods designed to optimize multiple objectives such as operational cost, CO_2 emissions, and system reliability. However, these approaches are often insufficiently validated with respect to energy demand sensitivity, limiting their robustness under dynamic and uncertain operating conditions. This study proposes an integrated energy forecasting and management framework that combines real-time energy management with intelligent load control based on dynamic building energy modeling. Despite significant progress in hybrid renewable energy system control, existing solutions frequently lack unified and computationally efficient algorithmic architectures capable of simultaneously addressing multiple renewable energy sources, energy storage systems, and demand response. Moreover, many approaches exhibit limited effectiveness in handling complex multi-objective optimization problems in real-time applications.

To overcome these limitations, the proposed framework integrates machine learning–based energy demand forecasting with a two-level optimization strategy supported by adaptive parameter control and parallel evaluation. The framework enables real-time decision-making while maintaining computational efficiency. By coordinating hybrid renewable energy systems with conventional power supply infrastructure, the proposed approach reduces carbon emissions and energy consumption while ensuring occupant comfort, thereby demonstrating strong potential for practical deployment in smart and energy-efficient buildings.

Keywords – Building dynamic simulation; building energy model; energy demand forecasting; hybrid renewable energy

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INTEGRATING METEOROLOGY AND HEALTH MODELLING: APPLICATION OF GAM AND DLNM APPROACHES TO PM2.5 POLLUTION IN SOUTH AND SOUTHEAST ASIA

Abhishek DUTTA[1*], Wanida JINSART[2]

[1,2] *Department of Environmental Science, Faculty of Science, Chulalongkorn University, 254 Phayathai Road, Pathumwan, Bangkok 10330, Thailand*

[*] ***Corresponding author.*** *Email address: abhishek.d@chula.ac.th*

Abstract – Meteorology has a decisive influence on the dispersion, transformation and health effects of air pollutants. In this research, the interaction between meteorological variability and air-pollution dynamics is examined by making a comparative study on two Asian cities, Delhi (India) and Nakhon Ratchasima (Thailand), that represent a different climatological regime. The analysis combines observational data and statistical modelling by means of Generalized Additive Models (GAM), Distributed Lag Models (DLM) and the Distributed Lag Nonlinear Models (DLNM) to quantify the short-term associations between the meteorological parameters, the particulate matter (PM2.5) and respiratory morbidity. Results show that meteorological factors such as boundary layer height, temperature inversions, humidity, and wind speed are a critical factor in the regulation of pollutant accumulation and exposure levels. In Delhi, winter boundary layers are shallow and in stagnation condition which further magnifies the PM2.5 concentration and leads to acute health response (RR = 1.06–1.83). On the contrary, the more moderate pollutant persistence by monsoonal meteorology of Nakhon Ratchasima results in smaller but longer lagged health effects (RR = 1.042–1.081 at lags 2–3 days). The DLNM approach was the best model fit and the approach included both non-linear exposure-response and delayed health impacts. In addition to emphasizing the importance of integrating meteorological variability into health-related studies, the paper also highlights the dynamic nature of meteorological variability as a determinant of air-quality episodes and health outcomes. Meteorological forecasting can be an important addition to air-quality management and health early-warning systems, which may significantly improve adaptive responses. The results can provide an empirical basis for the development of climate-informed mitigation of air pollution throughout tropical and continental Asia.

Keywords – Air pollution; Distributed Lag Nonlinear Model (DLNM); meteorology; $PM_{2.5}$

Meteorology-PM2.5-health interactions

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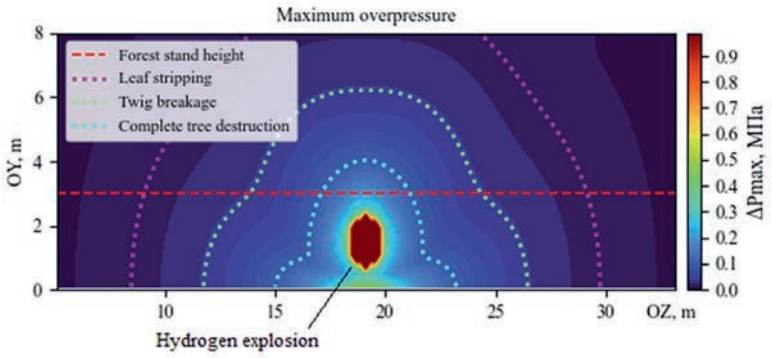
COMPUTATIONAL MODELING OF FOREST FIRE BARRIERS GENERATED BY HYDROGEN EXPLOSION SHOCK WAVES

Yurii SKOB[1*], Oksana PICHUGINA[2], Sergiy YAKOVLEV[3], Oleksii KARTASHOV[4]

[1,2,4] *Kharkiv National Aerospace University, 17, Vadym Manko Str., 61070 Kharkiv, Ukraine*
[3] *Karazin Kharkiv National University, 4 Svobody Sq., Kharkiv 61022, Ukraine*
[*] ***Corresponding author.*** *Email address: y.skob@khai.edu*

Abstract – The work presents the results of a numerical study of the spatiotemporal impact of a hydrogen hose charge blast wave on a forest massif to assess the possibility of forming firebreak streaks using a controlled pulse load. The study's relevance arises from the increase in the frequency and scale of forest fires under climate change, which requires the development of new technological solutions to localize their spread with minimal environmental impact. A set of several explosion power configurations (differing in hose-type charge radius) for modelling the hydrogen blast near the ground surface was examined. For each configuration, the spatial distributions of the maximum overpressure and the positive impulse of the shock wave were analyzed within the computed "air-forest cover" domain. Environmental blast impact parameter fields were generated from a hydrogen explosion model and analyzed, accounting for a given forest stand height. Based on maximum overpressure thresholds, zones corresponding to different levels of vegetation damage, including leaf stripping, twig breakage, and complete tree destruction, were identified. The extent of each zone along the ground surface was defined, enabling the quantification of the potential firebreak streak width. A comparative analysis of damage-zone widths as a function of the charge's geometric parameter (hose radius) was performed. Additionally, the time histories of overpressure at a characteristic point near the ground surface beneath the charge were analyzed for all modeling configurations, enabling a comparison of shock-wave dynamics at different explosion powers. Grouped bar charts and trends illustrating the dependence of the impact-zone widths on the radius of the hose-type charge were constructed. The results demonstrate the fundamental feasibility of controlling the extent of damage zones in forest vegetation by selecting hydrogen charge geometric parameters, thereby establishing a scientifically grounded basis for the development of environmental safety technologies for fire barrier formation.

Keywords – Controlled explosion impact; environmental safety; fire barrier formation; forest fires; hydrogen hose-type charge; maximum overpressure; positive phase impulse; shock wave pressure history; vegetation damage zones



Forest vegetation damage zones generated by the controlled hose-type hydrogen charge explosion

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HIGH RESOLUTION ATTRIBUTION-BASED ACCOUNTING OF ELECTRICITY CONSUMPTION RELATED GHG EMISSIONS IN LATVIA

Maksims FEOFILOVS[1*], Pauls SONDORS[2], Agris KAMENDERS[3], Francesco ROMAGNOLI[4]

[1,3,4] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia*

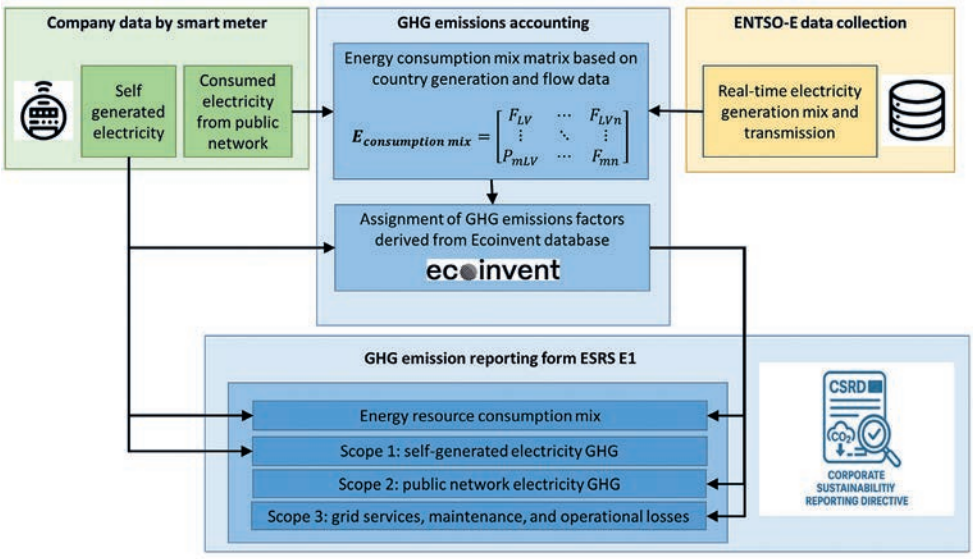
[2] *SIA AdvanGrid, Katlakalna iela 11, LV-1073, Riga, Latvia*

[*] ***Corresponding author**. Email address: maksims.feofilovs@rtu.lv*

Abstract – The implementation of the European Sustainability Reporting Standards (ESRS) for reporting under the Corporate Sustainability Reporting Directive (EU) 2022/2464 (CSRD) will substantially increase the demand for transparent, consistent, and methodologically robust greenhouse gas (GHG) accounting at the company level. It is expected that the upcoming ESRS E1 standard for climate disclosures will introduce detailed quantitative requirements related to energy consumption, including Scope 1, Scope 2 and Scope 3 emissions as referred in GHG protocol. Within the given frame of standards, electricity is one of the most widely consumed energy carriers across sectors and falls under Scope 2 emissions accounting and reporting. A tool for accounting electricity-related emissions under different market conditions for companies seeking to improve the accuracy of their climate reporting and perform better-informed carbon footprint management decisions. This study presents the development and application of a digital CO_2 emission accounting tool for electricity consumption within Latvia, designed to support companies in meeting the upcoming standard requirements for GHG emissions associated with purchased electricity. The methodological design of the developed tool combines corporate GHG accounting principles with electricity transmission system data and Scope 2 emissions data based on life cycle assessment (LCA) database Ecoinvent. The electricity generation emissions data are extracted from the Ecoinvent database for electricity generation types determined as significant for Latvia based on Nordpool market exchange and including Latvia, Lithuania, Estonia, Finland, Poland, Sweden, Norway and Denmark. The hourly cross-border physical flow data is further obtained from the ENTSO-E Transparency platform and processed using an attribution matrix, allowing the allocation of generated and transmitted electricity to geographical origins. Additionally, based on Ecoinvent data, the tool foresees Scope 1 emissions for onsite-generated electricity and Scope 3 emissions accounting for grid services, maintenance, and operational losses related to but not covered by Scope 2. The results demonstrate that the applied approach enables more precise estimation of electricity-related emissions than static national-average factors, particularly by tracking cross-border electricity trade. The separation of fossil and biogenic CO_2 flows, as well as the explicit treatment of CO_2 uptake. The tool provides real-time structured outputs aligned with ESRS E1 requirements and facilitates direct integration into sustainability reports. The study concludes that combining high-resolution electricity system data with LCA-based emission factors significantly enhances the accuracy and credibility of electricity emission data for corporate GHG accounting under ESRS. The proposed tool offers a practical solution for companies facing increasing reporting obligations, while also supporting internal decision-making related to energy sourcing and decarbonization

strategies. Further development should focus on consistent treatment of contractual instruments such as renewable energy certificates.

Keywords – Corporate sustainability; energy management; ESG; LCA; organisation carbon



Framework of the digital CO_2 emission accounting tool for electricity consumption

ACKNOWLEDGEMENT

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DEVELOPMENT OF A VEHICLE-LEVEL CAN-BASED LOGGING FRAMEWORK FOR A LOW-VOLTAGE ELECTRIC UNMANNED GROUND VEHICLE

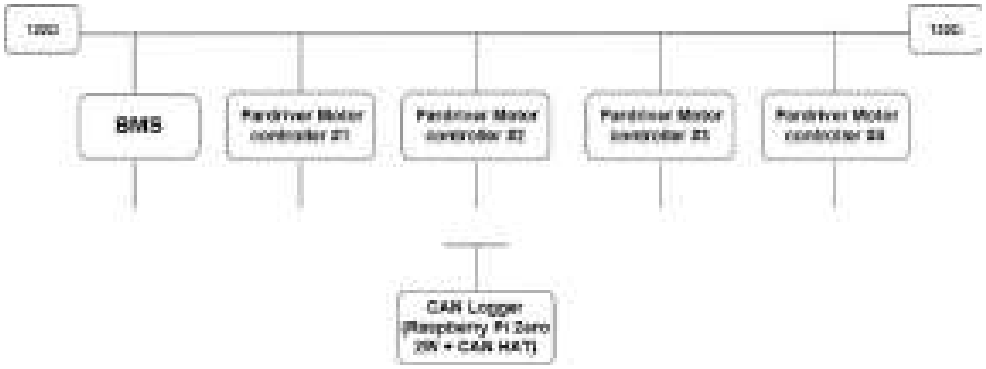
Magnus HIIE[1*], Tormi LILLERAND[2]

[1,2] *Estonian University of Life Sciences, Fr. R. Kreutzwaldi 56, 51006, Tartu, Estonia*

[*] ***Corresponding author.*** *Email address: magnus.hiie@emu.ee*

Abstract – Electric unmanned ground vehicles (UGVs) increasingly consist of multiple distributed electronic subsystems responsible for traction control, battery management, and diagnostics. These subsystems typically communicate via the Controller Area Network (CAN), which enables reliable data exchange but also introduces challenges related to data volume, interpretability, and auxiliary energy consumption. Existing CAN-based logging solutions often focus on individual subsystems, most notably the battery management system (BMS), and therefore provide limited insight into vehicle-level operating conditions. This work presents the design and system-level integration of a vehicle-oriented CAN-based logging framework for a low-voltage electric UGV. The target platform is a four-wheel-drive vehicle equipped with hub motors, individual motor controllers, and a low-voltage traction battery, where all subsystems communicate over a shared CAN network with termination at both physical ends. All control subsystems are connected directly to the main bus, while a low-power embedded CAN logger is attached via a short stub and operates as a passive monitoring node. Instead of employing a dedicated vehicle control unit, vehicle operating states are inferred in software using CAN messages originating from the BMS and motor controllers. High-level operating states, including OFF, IDLE, DRIVE, CHARGING, and FAULT, are defined to provide contextual information for the interpretation of energy usage and diagnostic events. The proposed framework introduces a state-aware logging concept in which CAN message selection, decoding, and storage behaviour are adapted according to the inferred vehicle state. The logging architecture distinguishes between raw CAN frame capture, decoded signal storage, and event-based snapshots, enabling selective data acquisition without modifications to the underlying communication network. The framework has been implemented and evaluated in a laboratory environment using real hardware components, including a low-power embedded logging unit and CAN-connected subsystems, allowing verification of data flows, state inference logic, and logging behaviour under representative operating conditions. The results indicate that integrating battery telemetry, traction-related data, and vehicle-level operating context enables a structured and scalable approach to CAN-based diagnostics in low-voltage electric UGV platforms. The proposed framework reduces system-level complexity and provides a solid foundation for extended experimental validation, energy efficiency analysis, fault diagnostics, and data-driven control strategy development.

Keywords – Embedded monitoring systems; energy usage analysis; state-aware data acquisition; subsystem telemetry



Physical CAN bus topology of the UGV logging system

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DEVELOPMENT IN MULTI-CRITERIA DECISION ANALYSIS RESEARCH

Beate ZLAUGOTNE[1]*, Julija GUSCA[2]

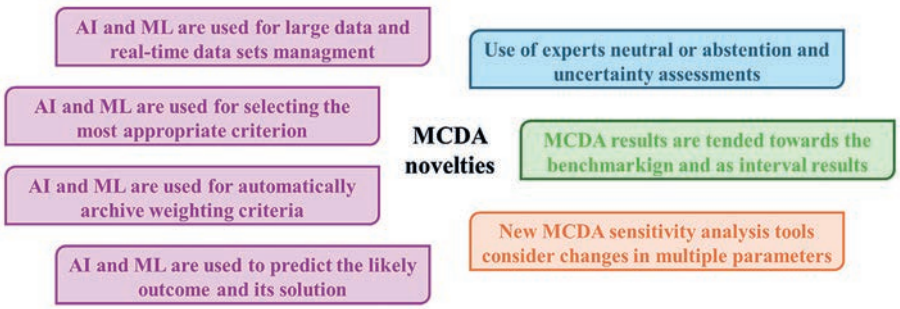
[1,2] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12-k1, Riga, LV1048, Latvia*

* ***Corresponding author.*** *Email address: beate.zlaugotne@rtu.lv*

Abstract – Multi-criteria decision analysis (MCDA) is used to solve complex and even contradictory problems by ranking them according to various quantitative and qualitative criteria. MCDA originated several decades ago but has become particularly popular in recent years and now includes more than 200 methods and combinations thereof. Initial MCDA applications were based on modeling preferences and appropriate decision-making based on several criteria, but over the years, development has moved from theoretical frameworks to widespread application and methodological growth. However, MCDA has also incorporated fuzzy sets, risk and uncertainty modelling and multi-criteria optimization, thereby expanding its applicability and scope. The research focuses on the development of MCDA over the last five years due to the rapid development of artificial intelligence and its tools. As a result, MCDA has evolved from a separate tool to a highly integrated system in its various stages:

- MCDA integration with artificial intelligence (AI) and machine learning (ML) as a filter for large data sets, deals with unstructured data, use real-time data for decision-making, helps to select the most appropriate criteria, learns from previous decision data to automatically archive weighting criteria, combines possible outcomes with possible actions in that case.
- MCDA calculation approach shifts from the most perfect result, which is often impossible, to a solution that is a reference to an existing good and realistic solution, also results can be as interval due to unclear approximate sets.
- Uncertainty in MCDA, as an opportunity for experts to express neutral or abstention assessments and for decision-makers to express dislike or uncertainty in their assessments, creates a broader mathematical space for defining opinions.
- Sensitivity analysis MCDA is also evolving, with new, more comprehensive sensitivity analysis methods that simultaneously consider multiple parameters and show the instability of such multiple criteria interactions, as well as the ability to show decision sensitivity in real time.

Keywords – Artificial intelligence integration; benchmark; sensitivity analysis; uncertainty of expert opinions



MCDA newest trends

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IMPROVING PRECISION OF CARBON EMISSIONS ACCOUNTING FOR SUSTAINABILITY REPORTING: CASE STUDY FROM LATVIA

Anete KALNINA[1*], Pauls SONDORS[2], Maksims FEOFILOVS[3], Agris KAMENDERS[4], Francesco ROMAGNOLI[5]

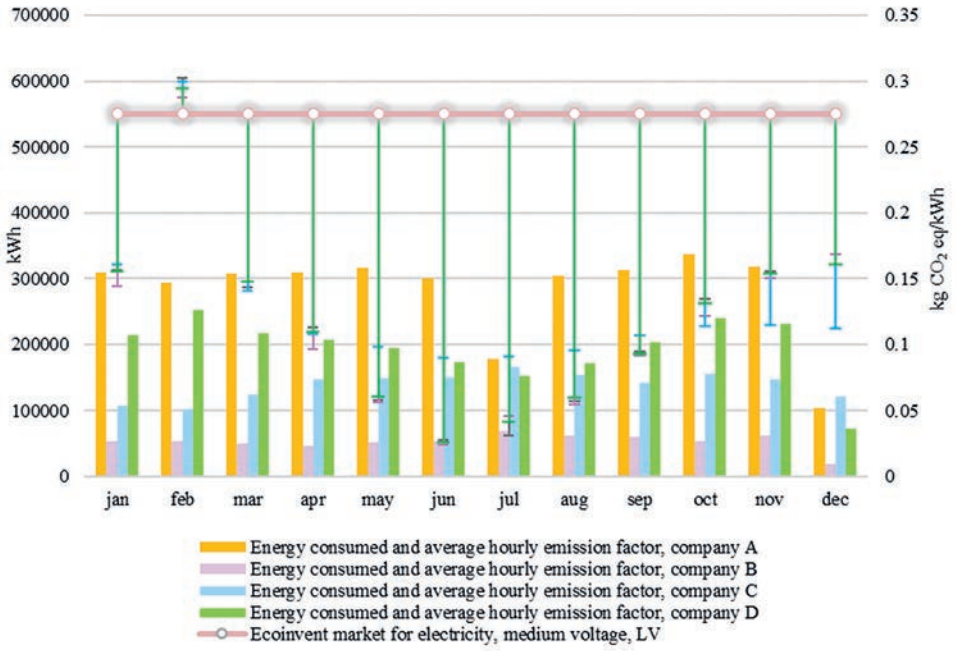
[1,3–5] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, LV-1048, Riga, Latvia*

[2] *SIA AdvanGrid, Katlakalna street 11, LV-1073, Riga, Latvia*

[*] ***Corresponding author.*** *Email address: anete.kalnina_2@edu.rtu.lv*

Abstract – Among growing regulatory and investor pressure for high-quality sustainability reporting, accurate carbon accounting has become essential for corporate Environmental, Social, and Governance disclosures. A key challenge exists in calculating consumed electricity-related emissions (Scope 2), where companies often rely on generalized national average emission factors, for which accounting approaches differ in how electricity generation, cross-border exchanges, and energy attributes are interpreted and allocated. Some methods primarily rely on nationally produced electricity as a proxy for consumption, while others incorporate electricity trade and contractual instruments to represent how energy is acquired and reported by companies. Even for two approaches defined by the GHG protocol, known as market-based mix accounting and location-based mix accounting, disparities appear in their interpretation. As concluded from studies on Norway's and Iceland's differences between nationally produced, exported and imported energy, the problem with accounting for location-based energy mixes (increasing double counting of renewable energy consumed by companies) has a higher impact on countries with a high share of renewable energy production, which export the produced energy and sell renewable energy certificates, such as Latvia. As a result, the choice of accounting method and data resolution plays a critical role in determining reported electricity-related emissions at the company level. This study aims to explore how an increase in the granularity of company-specific electricity consumption measured data can improve the precision and traceability of related Scope 2 emissions for more qualitative operational decisions in companies. A case study was conducted using hourly sensor-measured electricity consumption data from four manufacturing companies that operate in Latvia over one year. The delivered electricity mix to the company was recorded each hour, and the company-specific average hourly and yearly emission factor was calculated. The results demonstrate that company-specific data typically yield lower calculated emission factors than the commonly used Ecoinvent database country-specific CO_2eq emission factor, i.e., company-specific yearly average emission factors were approximately 56 % lower. However, these results must further be contextualized within the methodological tensions between physical location-based and contractual market-based energy mix accounting. This study supports the current need for harmonized, high-resolution energy data practices and integration with digital solutions to support trustworthy carbon emissions disclosures.

Keywords – Corporate sustainability reporting; energy mix; ESG; GHG protocol; guarantees of origin; IoT; LCA; renewable energy certificates; Scope 2



Energy consumed and average calculated hourly emission factors as deviations from Ecoinvent market for medium voltage electricity factor for Latvia in 2025

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TOWARDS A FRAMEWORK FOR EXERGY-BASED LIFE CYCLE ASSESSMENT

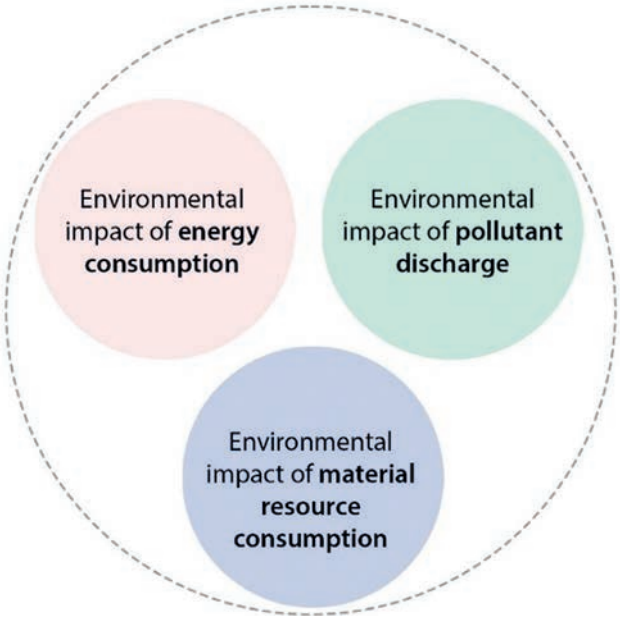
Samira SHOKOUHI[1*], Ingo WEIDLICH[2]

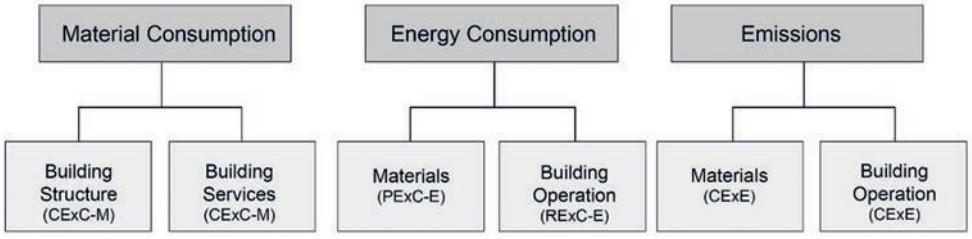
[1,2] *HafenCity University Hamburg, Henning-Voscherau-Platz 1, 20457 Hamburg, Germany*

[*] ***Corresponding author.*** *Email address: samira.shokouhi@hcu-hamburg.de*

Abstract – Life cycle assessment (LCA) is widely used to evaluate the environmental performance of buildings, yet it struggles to capture energy quality, thermodynamic irreversibility and physically grounded resource scarcity. This article proposes a comprehensive exergy based LCA methodology for buildings and contrasts it with conventional, characterization factor-dependent LCA indicators. The approach builds on an extensive review of exergy concepts and their integration into LCA for the built environment, leading to a method that combines physical and chemical resource exergy analysis with a cradle to grave building LCA. The analysis adopts a functional unit of 1 m^2 reference area over 50 years, while life cycle processes are explicitly separated into recurring (operational energy and related emissions) and non-recurring (material production, construction, replacements) elements to ensure consistent scenario comparison. The developed framework introduces additional indicators beyond conventional LCA: Chemical Exergy Consumption of Materials (CExC-M) which reflects both quantity and concentration of resources, Resource Exergy Consumption of Energy (RExC-E) which distinguishes between storable (on-demand) and non-storable (transient, non-dispatchable) energy forms, Primary Exergy Consumption of Energy (PExC-E), and Chemical Exergy of Emissions (CExE) expressing the work potential of pollutants discharged to the environment. These aggregate into the Overall Exergy Impact (OExI). By excluding solar, wind and similar non storable flows, the method avoids overemphasizing renewable exergy inputs and focuses on resources that are actually depleted or stored in building systems. Compared to conventional impact category indicators such as global warming potential or abiotic depletion potential, OExI provides a single, unified, thermodynamically objective scale that links material, energy and emission domains without subjective weighting, capturing energy quality, and quantifying material scarcity. Methodological prerequisites include: consistent, substance level inventory data for materials, fuels and emissions; clear reference environment definitions for all exergy calculations; transparent treatment of recurring versus non-recurring processes; and explicit disclosure of assumptions where different exergy approaches (e.g., resource exergy analysis for operations, primary energy-based exergy for materials, literature chemical exergies) are combined. Under these conditions, the proposed exergy based LCA framework can reveal tradeoffs hidden in conventional LCA, support more robust design decisions, and lay the groundwork for integrating thermodynamically rigorous indicators into future building sustainability assessments.

Keywords – Exergetic Life Cycle Assessment; environmental indicators, Overall Exergy Impact, Resource Exergy Analysis





Life Cycle Exergy Impact and Indicators

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SLIDING MULTIFRACTAL ANALYSIS OF AIR POLLUTION TIME SERIES FOR ANOMALY DETECTION AND ENVIRONMENTAL MONITORING

Lyudmyla KIRICHENKO[1], Olha MATSYI[2], Sergiy YAKOVLEV[3]

[1] *Lodz University of Technology, ul. Żeromskiego 116, 90-924 Lodz, Poland*
[1–3] *V.N. Karazin Kharkiv National University, 4 Svobody sq., 61022 Kharkiv, Ukraine*
* ***Corresponding author.*** *Email address: lyudmyla.kirichenko@p.lodz.pl*

Abstract – This study investigates the fractal and multifractal properties of time series of atmospheric pollutant concentrations. It is demonstrated that these characteristics exhibit pronounced self-similarity, long-term correlation memory, and complex scaling behavior. The temporal evolution of fractal parameters serves as a sensitive indicator of both natural and anthropogenic changes in air pollution dynamics, including subtle structural rearrangements that are poorly detectable using conventional statistical methods. A sliding monitoring approach for fractal characteristics is proposed and implemented. The original time series is analyzed in sequentially shifted windows of fixed length with a specified overlap step. In each window, the multifractal detrended fluctuation analysis (MF-DFA) method is applied to compute key metrics: the generalized Hurst exponent, multifractal spectrum width, degree of multifractality, and other measures of scaling inhomogeneity. The resulting estimates form new time series of parameters that reflect the dynamics of the correlation structure and scaling properties of the original data. The analysis results show that anomalous episodes (periods of intense smog, sharp industrial or transport emissions) are accompanied by significant changes in fractal indicators: shifts in the Hurst exponent, expansion or contraction of the multifractal spectrum, and increased degree of inhomogeneity. These changes enable the detection not only of obvious anomalies but also of more subtle structural rearrangements in pollution time series. The obtained results open prospects for applying the proposed approach not only to early detection of anomalous events and comprehensive assessment of atmospheric air quality, but also to optimizing the coverage of environmental monitoring networks. The temporal evolution of fractal metrics can serve as an indicator of zones with increased inhomogeneity and non-stationarity in pollution dynamics, where higher sensor density or resource reallocation is required. This is particularly relevant for modern hybrid systems based on low-cost sensors and IoT technologies. Thus, sliding multifractal analysis contributes to more effective, targeted, and equitable air quality monitoring in urbanized regions.

Keywords – Air pollution; anomaly detection; environmental monitoring; Hurst exponent; MF-DFA; sensor coverage; time series

ACKNOWLEDGMENT

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COMPUTATIONAL MODEL FOR PREDICTING THE REMAINING BATTERY ENERGY OF AN UNMANNED AGRICULTURAL GROUND VEHICLE

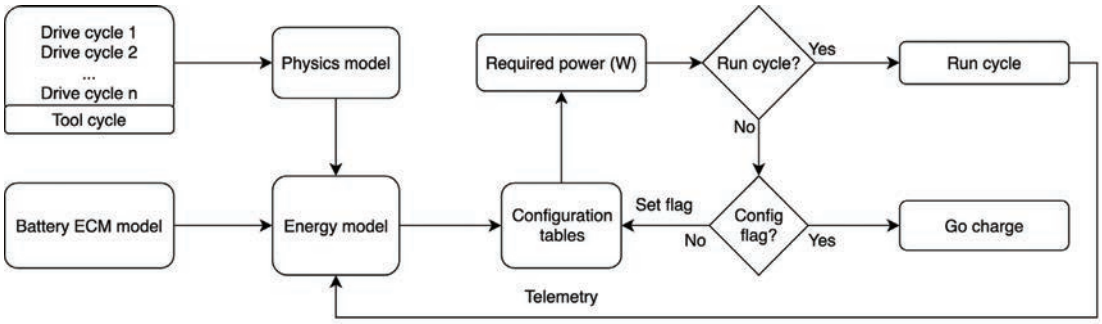
Andreas MUGRA[1*], Olga LIIVAPUU[2], Yevhen IHNATIEV[3], Tormi LILLERAND[4]

[1–4] *Estonian University of Life Sciences, Fr. R. Kreutzwaldi 56, 51006, Tartu, Estonia*

[*] ***Corresponding author.*** *Email address: andreas.mugra@emu.ee*

Abstract – This paper presents a computational model and an approach for predicting the remaining battery energy of an autonomous unmanned ground vehicle (UGV) used for fertilizer application in blueberry plantations under the soil conditions of drained peatlands. The primary objective of the study is to optimize battery operating modes by reducing non-productive energy consumption, justifying an appropriate depth of discharge, and extending the service life of the energy storage system. To achieve this, a computational model for energy consumption estimation and prediction is proposed, enabling an optimal for battery operating regime of the field UGV under operator defined constraints. The developed model supports dynamic adaptation of work cycles, minimizes non-productive motion, and maintains the state of charge within ranges that are optimal for the specific battery chemistry. The proposed approach combines a rolling resistance based vehicle motion model with a temperature dependent Thevenin equivalent circuit model (ECM) of the battery pack. Based on a set of typical duty cycles, the developed vehicle model determines the mechanical power required for the planned operation. Battery parameters are obtained from cell characterization data, including the open-circuit voltage-state of charge (OCV–SOC) relationship, ohmic resistance, and polarization dynamics. The state of charge and polarization effects are estimated using an extended Kalman filter (EKF), which is driven by measured current and corrected using voltage measurements with temperature dependent parameter scaling. To reconcile the calculated energy demand with measurement results, a drivetrain efficiency map dependent on speed and torque was developed. This map was identified using controller area network (CAN) bus, IMUs, and current measurement data by comparing the predicted mechanical power with the measured electrical power. The resulting efficiency map captures losses in the hub motors, power controllers, wiring, and auxiliary systems, and is used for mission simulation and real-time prediction of voltage, power, and remaining usable energy under alternative combinations of drive cycles. The approach was validated on an autonomous agricultural UGV developed by the Field Robotics Research Group of the Estonian University of Life Sciences. The platform is equipped with four 48 V, 1 kW hub motors, an onboard computing system based on two Raspberry Pi Zero 2W units, CAN communication, motion sensing via OpenLog Artemis IMUs, and a lithium-ion battery pack based on Samsung SDI 94 Ah cells.

Keywords – Autonomous agricultural robotics; equivalent circuit models; extended Kalman filter; mission-aware energy estimation; power consumption models; power management optimization



Flow diagram of computational model

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DYNAMIC MODELING AND EXPERIMENTAL VALIDATION OF A PEM-BASED SYSTEM INTEGRATED WITH RENEWABLE POWER SOURCES

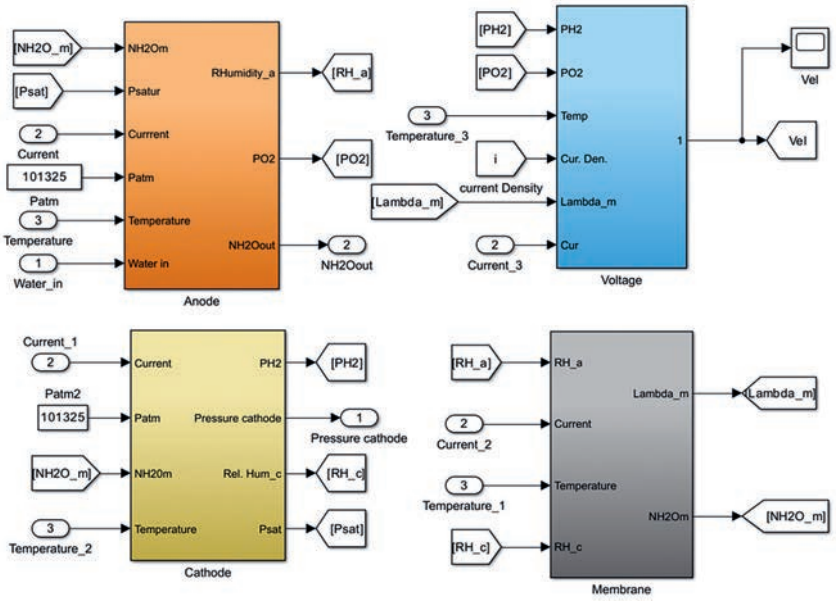
Nayrana DABORER-PRADO[1*], Lukas GAISBERGER[2]

[1,2] *University of Applied Sciences Upper Austria, Research group ASIC, Stelzhamerstraße 23, Wels, Austria*

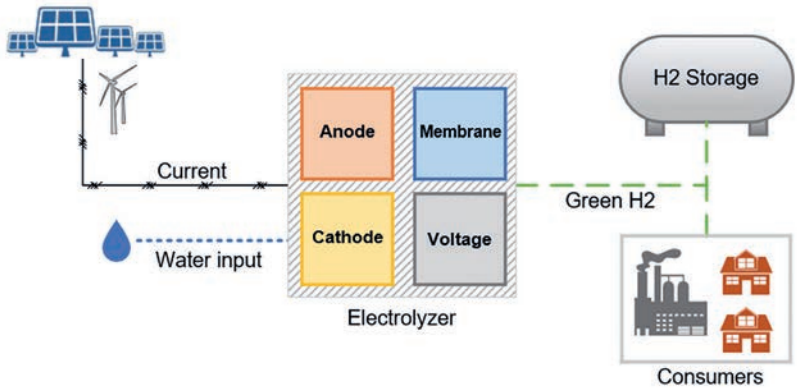
[*] ***Corresponding author.*** *Email address: Nayrana.daborer-prado@fh-wels.at*

Abstract – In recent years, hydrogen (H_2) has gained significant attention as a key element in the global energy transition due to its potential to reduce carbon emissions and support sustainable energy systems. Governments and industries have increasingly invested in hydrogen technologies to decarbonize sectors such as transportation, industry, and power generation. Hydrogen can be classified according to its production pathway into gray, blue, brown/black, and green hydrogen, with green hydrogen representing the most environmentally sustainable option and the focus of this study. Green hydrogen is produced via water electrolysis powered by renewable energy sources, using surplus energy from wind, solar, or hydropower to split water into hydrogen and oxygen. This process is carried out by electrolyzers, with the main types being proton exchange membrane (PEM), alkaline, and solid oxide electrolyzers. Among these, PEM electrolyzers offer notable advantages, particularly in renewable energy applications. They respond quickly to power fluctuations, produce high-purity hydrogen suitable for fuel cells, and feature compact designs capable of operating at higher current densities. Owing to these advantages, this study focuses on PEM electrolyzers and their integration with renewable energy sources. The first stage of this study involves the development of a detailed mathematical model of the electrolyzer. To accurately capture the dynamic interactions within the system, the PEM electrolyzer model is structured into four interconnected submodels: the anode, cathode, membrane, and voltage components (Figure (a)). The system is implemented in MATLAB/Simulink®, with current (A), water mass flow rate ($kg \cdot s^{-1}$), pressure (Pa), and temperature (°C) defined as the primary input variables. In the second stage, the simulation results are validated against experimental data obtained from a prototype operating at the Hydrogen Center laboratory. Finally, the validated electrolyzer model is integrated into an energy-hub framework that incorporates renewable energy sources, hydrogen storage systems, and multiple categories of end users, including industrial and residential consumers as depicted in Figure (b).

Keywords – Electrolysis; energy storage; green-gases; hydrogen production; sector coupling



Simulink view of the electrolyzer model



Integration of the electrolyzer in an energy-hub

ACKNOWLEDGEMENT

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MODELING AND PREDICTION OF PM2.5 USING DIFFERENT DEEP LEARNING TECHNIQUES: A COMPARATIVE ANALYSIS

Murad A. YAGHI[1*], Huthaifa AL-OMARI[2], Salem ALEMAISHAT[3]

[1] *Data Science and Artificial Intelligence Department, Al-Hussein Technical University, King Hussein Business Park, Amman, Jordan*

[2,3] *Computer Science Department, Al-Hussein Technical University, King Hussein Business Park, Amman, Jordan*

[*] ***Corresponding author.*** *Email address: murad.yaghi@htu.edu.jo*

Abstract – Accurate forecasting of fine particulate matter ($PM_{2.5}$) concentrations is essential for public health protection and environmental management. While deep learning approaches have shown promise for $PM_{2.5}$ prediction, consistent comparative evaluations under standardized conditions remain limited. This paper presents a comprehensive performance analysis of three widely adopted sequence forecasting architectures: Long Short-Term Memory (LSTM), Gated Recurrent Unit (GRU), and Neural Basis Expansion Analysis for Time Series (N-BEATS), for short-term $PM_{2.5}$ concentration prediction. All models were trained and evaluated under identical experimental conditions using a 70/15/15 train-validation-test split across four input window lengths (5, 10, 15, and 20 hours). Our results demonstrate that extending the temporal context systematically improves predictive accuracy, though marginal gains diminish beyond 15–20 time steps. N-BEATS consistently outperformed both recurrent architectures across all metrics and window sizes, achieving a root mean square error (RMSE) of 55.28 μg/m^3 and R^2 of 0.5116 at the 20-step horizon representing a 14 % reduction in RMSE compared to GRU and superior reproduction of hazardous pollution episodes. Additionally, N-BEATS exhibited substantially faster training times and near-constant computational costs across window sizes, whereas LSTM and GRU training times increased three-fold. The feed-forward, block-based architecture of N-BEATS enables highly parallelized computation while its interpretable basis-function decomposition better captures abrupt nonlinear patterns inherent in pollution dynamics. These findings establish N-BEATS as a computationally efficient and accurate choice for real-time air quality forecasting systems, while highlighting the importance of standardized evaluation protocols for advancing atmospheric time-series prediction.

Keywords – GRU; LSTM; N-BEATS; particulate matter; time series forecasting

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NONLINEAR DRIVERS OF ENVIRONMENTAL SUSTAINABILITY IN ITALY: EVIDENCE FROM A QUANTILE-BASED FRAMEWORK

Aamir JAVED[1], Agnese RAPPOSELLI[2*]

[1] *Department of Economic Studies, University "G. D'Annunzio" of Chieti-Pescara, Viale Pindaro 42, 65127 Pescara, Italy*

[2] *Department of Management and Business Administration, University "G. D'Annunzio" of Chieti-Pescara, Viale Pindaro 42, 65127 Pescara, Italy*

[*] ***Corresponding author.*** *Email address: agnese.rapposelli@unich.it*

Abstract – Ensuring environmental sustainability in advanced economies such as Italy is a prerequisite for achieving sustained economic development while preserving ecological balance and long-term environmental resilience. Consequently, policymakers and environmental stakeholders face a pressing need to identify new factors that can effectively enhance environmental sustainability, particularly in the context of rapid technological advancement, the expansion of green-oriented financial activities, and increasing geopolitical uncertainty. While previous studies have examined the linear relationship between environmental sustainability and its determinants, there remains a gap in the literature regarding nonlinear and asymmetric associations. The present study therefore explores the asymmetric effects of artificial intelligence innovation, energy technology development, green finance, and environmental governance on environmental sustainability in Italy, while controlling for economic growth, geopolitical risk, and natural resource rents. To accomplish this, we adopt innovative quantile-based econometric methodologies, including quantile cointegration techniques, to capture asymmetric long-run relationships across different states of environmental sustainability, by using time-series data for Italy. The results indicate that artificial intelligence, energy technology, green finance, economic growth, and geopolitical risk exhibit a strong asymmetric association with environmental sustainability, as measured by the Load Capacity Factor (LCF). In particular, excessive economic growth and heightened geopolitical risk tend to exacerbate environmental pressure when environmental sustainability is weak. Technological advancement and green financial development do not uniformly enhance environmental sustainability under conditions of severe ecological stress. By contrast, natural resource rents contribute to improving environmental sustainability by alleviating environmental pressure. Our findings corroborate that moderate advancement in artificial intelligence, energy technology, and green finance can help improve Italy's environmental sustainability without intensifying ecological degradation. Accordingly, Italian policymakers should place greater emphasis on mitigating the negative spillover effects arising from excessive economic expansion and geopolitical instability, while also accounting for other ancillary factors that interact closely with technological and financial development. Moreover, strengthening environmental governance before environmental pressure reaches critical levels is crucial for ensuring long-term ecological resilience and sustainable development in Italy.

Keywords – Artificial intelligence; environmental sustainability; green finance; Load Capacity Factor (LCF); quantile-based analysis

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3D MODELING OF EXTREME EVENT SCENARIO SELECTED HERITAGE BUILDING

Michal HULIAK[1*], Michal MIŠKE[2], Dominik ŠPILÁK[3]

[1,2] *University of Žilina, Faculty of Security Engineering, Univerzitná 8215, 010 26, Žilina, Slovakia*
[3] *Department of Fire Protection, Faculty of Wood Sciences and Technology, Technical University in Zvolen, 960 01 Zvolen, Slovakia*
[*] ***Corresponding author.*** *Email address: michal.huliak@uniza.sk*

Abstract – Preserving the load bearing elements of heritage timber structures is essential for their survival during extreme-event scenarios such as fire. However, the application of fire protection systems can compromise the building's historic appearance, making it important to determine when such measures are necessary. This study used Ansys Mechanical to model the response of a heritage timber structure to extreme fire conditions, simulating heat transfer and estimating the resulting charred cross section. Model inputs were derived from medium scale fire tests on original timber beams. The results identified fire scenarios in which structural elements retain sufficient load bearing capacity without additional protection, thereby pinpointing which components require supplementary measures and minimizing unnecessary interventions.

Keywords – 3D modeling; extreme event scenario; fire modelling, fire test; heritage timber buildings

ACKNOWLEDGEMENT

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WELL-TO-PORT ASSESSMENT OF HYDROGEN PRODUCTION PATHWAYS FOR SEAPORT DECARBONIZATION

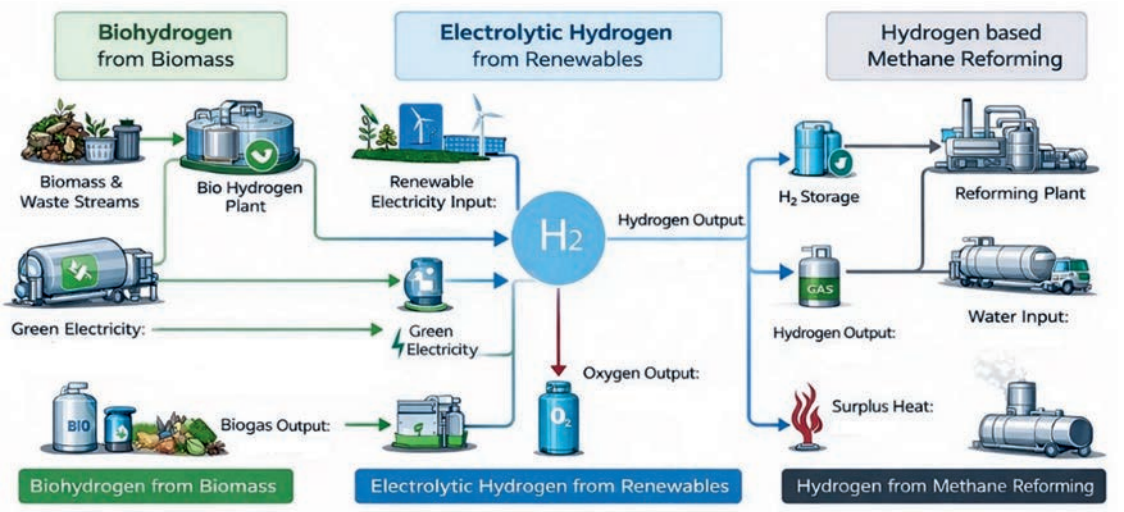
Aivis KĻAVIŅŠ[1]*, Vladimirs KIRSANOVS[2], Maksims FEOFILOVS[3]

[1–3] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, LV-1048 Riga, Latvia*

* ***Corresponding author.*** *Email: aivis.klavins97@gmail.com*

Abstract – This research investigates hydrogen production and supply chains integrated within seaport environments using a well-to-port perspective to support the decarbonization of maritime and port-related activities. Three hydrogen production pathways are analysed: biohydrogen derived from biomass and waste streams, electrolytic hydrogen produced using renewable electricity, and methane-based hydrogen generated through reforming processes. Hydrogen transportation from production sites to the port area is included within the well-to-port system boundary and assessed through pipeline transport, road-based delivery, and on-site production options. The results are based on scenario modelling performed with the energyPRO software, which was used to quantify key input and output parameters for each production pathway. Model outputs include hydrogen production volumes, energy and feedstock inputs, electricity demand, process efficiencies, and associated by-products, providing a detailed comparison of system performance across scenarios. Environmental impacts are calculated using methods consistent with the Product Environmental Footprint (PEF) framework and emission factors aligned with Intergovernmental Panel on Climate Change (IPCC) guidelines. In accordance with EU PEF Category Rules principles, the functional unit is defined as 1 MJ of hydrogen energy (lower heating value) delivered to the seaport gate at the specified purity and pressure. The results highlight differences in resource use, energy intensity, and environmental performance among the assessed hydrogen production pathways.

Keywords – Hydrogen production; product environmental footprint; seaport decarbonisation; well-to-port



OpenAI, "Hydrogen production pathways diagram", AI-generated image, ChatGPT (DALL·E), 2026

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A LIFE CYCLE ASSESSMENT BASED COMPUTATIONAL FRAMEWORK FOR INLAND CO_2 TRANSPORTATION BY TRUCKS

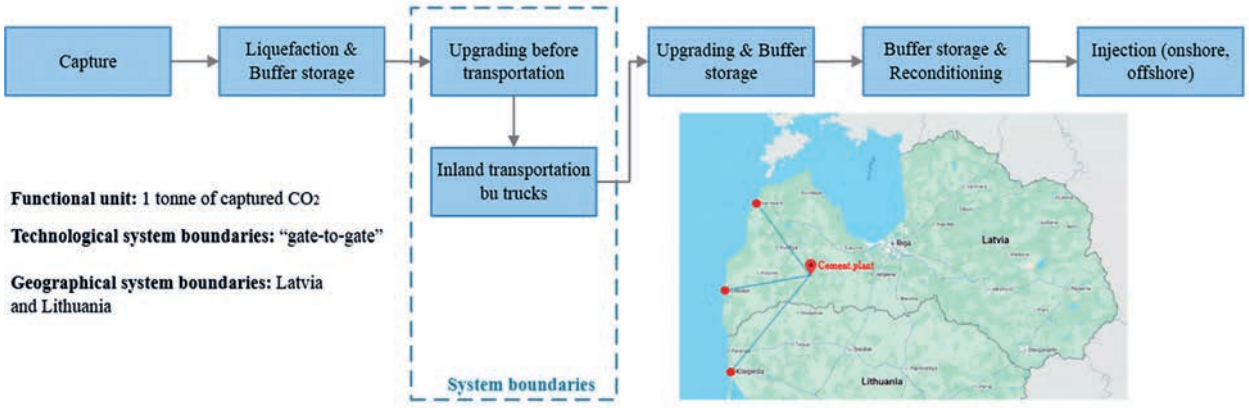
Mikus DZENIS[1], Beate ZLAUGOTNE[2], Jūlija GUSCA[3]*

[1–3] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, LV-1048, Riga, Latvia*

* ***Corresponding author.*** *Email address: julija.gusca@rtu.lv*

Abstract – Achieving net-zero emissions targets for industries (especially hard-to-abate) has positioned carbon capture, utilization and storage (CCUS) as emerging CO_2 reduction technology in Europe with rapid growth of research and pilot projects in recent years. The scope of ongoing CCUS projects is expanding to include both CO_2 utilization as a feedstock for industrial applications (including chemicals, steel, construction, textiles, energy storage and renewable energy sectors) and CO_2 geological storage. In the context of geological storage in the Nordic–Baltic region, a significant initiative in this context is the actively developing "Northern Lights" project. Despite the promising potential of CCUS for mitigating CO_2 emissions, the CO_2 reduction potential across the entire supply chain must be clearly defined to ensure a cumulative net reduction. Specifically, the balance of stored or utilized CO_2 should be genuinely negative after accounting for the CO_2 emissions generated within the CCUS supply chain itself. One of the methodological tools employed to address this issue is life cycle assessment (LCA). Within the scope of the present research, an LCA-based computational framework for the transportation of CO_2 captured from industrial sources is developed. A case study is conducted for Latvia, where the source of captured CO_2 is a local cement producer. The captured CO_2 is transported under three alternative scenarios to the ports of Liepaja and Ventspils in Latvia, and to the port of Klaipeda in Lithuania, for subsequent marine transportation to offshore geological storage. In addition, the study is supplemented by a sensitivity analysis addressing transport-related parameters, including fuel types, vehicle technologies and CO_2 flow specifics.

Keywords – Carbon capture and storage; CO_2 inland transport; sustainability assessment



System boundaries for environmental assessment of CO_2 transportation by trucks

ACKNOWLEDGEMENT

This research is funded by the project “Efficient and Sustainable Maritime Infrastructure for CCS Logistics in the Nordic and Baltic Countries (LogiCCS)” under the Clean Energy Transition Partnership within the 2024 joint call for research proposals. The project is co-funded by the European Commission (Grant Agreement No. 101069750) and the national funding organizations listed at: https://cetpartnership.eu/funding-agencies-and-call-modules.

03

BIOTECHNOLOGIES, BIORESOURCES

https://doi.org/10.7250/CONECT.2026.045

VALORIZATION OF PHYTOREMEDIATION BIOMASS FOR BIOGAS PRODUCTION: ADVANCING A CIRCULAR ECONOMY APPROACH TO MINE TAILINGS REHABILITATION IN SOUTH AFRICA

Nkanyiso Mlalazi[1], Charles Mbohwa[2], Shumani Ramuhaheli[3]

[1,3] *Department of Mechanical, Bioresources & Biomedical Engineering, School of Engineering, University of South Africa, Roodepoort, Johannesburg 1709, South Africa*

[2] *Department of Industrial Engineering, School of Engineering, University of South Africa, Roodepoort, Johannesburg 1709, South Africa*

* ***Corresponding author.*** *Email address: mlalan1@unisa.ac.za*

Abstract – Since the inception of phytoremediation in South Africa, plant species selection has predominantly been guided by biodiversity conservation criteria, particularly the use of indigenous species capable of surviving on mine tailings while stabilizing or extracting contaminants. While this approach has supported ecological restoration objectives, it has largely overlooked the potential for integrating circular economy principles, such as reuse, recycling, and cradle-to-cradle material flows, into mine rehabilitation practices. Consequently, mine waste and associated phytoremediation biomass continue to be treated as residual waste streams, despite evolving sustainability perspectives. Regulatory frameworks have similarly remained largely stagnant in recognizing mine waste as a potential resource. This study explores a deliberate shift in phytoremediation strategy by assessing the use of bioenergy plants for mine tailings rehabilitation in South Africa, with the explicit aim of enabling post-harvest biomass valorization. Vetiver grass (*Chrysopogon zizanioides*), a high-biomass, stress-tolerant species, was cultivated on gold mine tailings located along the border of the North West and Gauteng provinces. Above-ground biomass was harvested and utilized as a feedstock for anaerobic digestion to evaluate its potential for renewable energy production. Biogas production experiments were conducted using the Automatic Methane Potential Test System (AMPTS II) under controlled laboratory conditions over a 50-day operational period. Continuous monitoring of biogas generation was performed to assess the biodegradability and energy recovery potential of vetiver grass biomass derived from contaminated substrates. The results indicate that vetiver grass grown on gold mine tailings is capable of producing biogas through anaerobic digestion, demonstrating successful conversion of phytoremediation biomass into renewable energy. Although detailed yield optimization and compositional analyses are ongoing, cumulative biogas production throughout the experimental period confirms the technical feasibility of this valorization pathway. The study provides evidence that incorporating bioenergy-oriented plant selection into phytoremediation frameworks can enhance the sustainability of mine rehabilitation by linking environmental remediation with resource recovery. This approach supports a transition from linear waste management toward circular economy practices and highlights the need for policy and regulatory reform to enable cradle-to-cradle implementation in mine tailings management.

Keywords – Anaerobic digestion; AMPTS II; bioenergy; biogas production; biomass valorization; circular economy; phytoremediation; sustainable mine rehabilitation; vetiver grass

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POLYPHENOLIC PROFILE OF INVASIVE PLANT – REYNOUTRIA SPP SPECIES

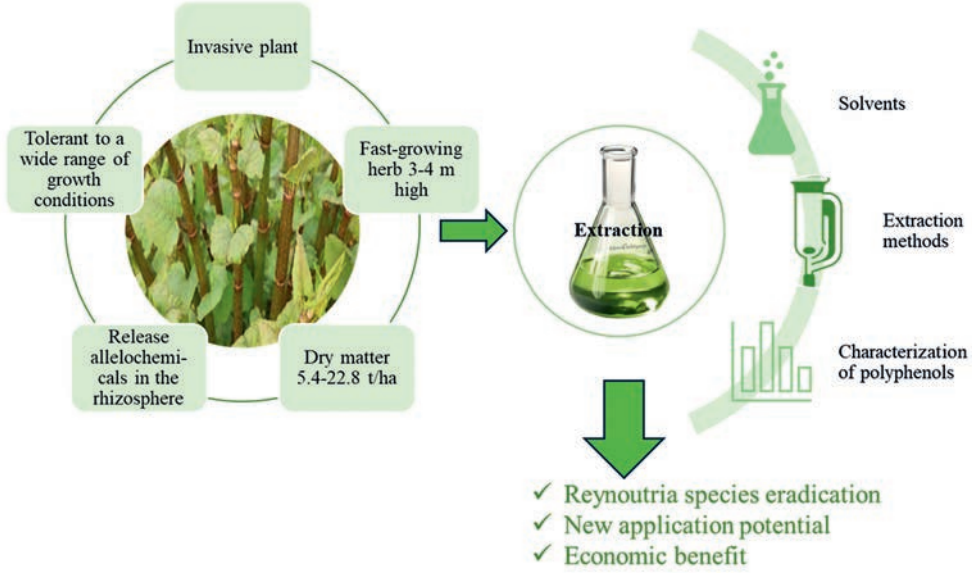
Linda ANSONE-BERTINA[1*], Linards KLAVINS[2], Jorens KVIESIS[3], Evelina NIEDRITE[4], Maris KLAVINS[5]

[1–5] *Department of Environmental Science, University of Latvia, Jelgavas str.1, Riga, Latvia*

[*] ***Corresponding author.*** *Email address: linda.ansone-bertina@lu.lv*

Abstract – The global spread of invasive plant species causes significant ecological, economic, and public health problems by disrupting ecosystems and reducing biodiversity. Species of the genus *Reynoutria* (knotweeds), including *Reynoutria japonica*, *Reynoutria sachalinensis*, and their hybrid *Reynoutria* × *bohemica*, are among the most invasive alien plant species of concern in the European Union. These plants are rich in polyphenols, a group of biologically active secondary metabolites with potential pharmaceutical and ecological value. The present study aims to develop an extraction, purification, and characterization approach for polyphenolic complexes from *Reynoutria* species, supporting invasive species management through the valorisation of biomass (Fig. 1). Polyphenol extraction was performed using different plant parts (roots, stems, and leaves, etc.) of three *Reynoutria* species, various solvents (methanol, ethanol, water, etc.), and several extraction techniques (maceration, Soxhlet extraction, ultrasound-assisted extraction, etc.). The yield of extractives was determined gravimetrically, total polyphenolic content was quantified using the Folin-Ciocalteu method, and antiradical activity was evaluated by DPPH assay. The chemical composition of selected extracts was analysed by GC–MS. The highest extraction yields were obtained from leaves of all studied species, followed by roots, while stems showed the lowest yields. Maximum extractive contents reached 238.85 mg/g for R. japonica, 220.72 mg/g for *R.* × *bohemica*, and 205.14 mg/g for R. sachalinensis leaves. Among the tested methods, Soxhlet extraction following maceration provided the highest yields and total polyphenolic content. *R. japonica* leaves exhibited the highest total polyphenolic content (89 ± 2 mg GAE/g dry matter) and the strongest antiradical activity (150 ± 4 mg trolox equivalents/g). Antiradical activity showed a strong correlation with polyphenol concentration in all samples. The results indicate that *Reynoutria* leaves and roots are valuable sources of polyphenolic compounds and that extraction efficiency strongly depends on the applied method and solvent. This study demonstrates the potential to transform invasive knotweed biomass into a source of bioactive compounds, thereby contributing to sustainable invasive species management strategies.

Keywords – Extraction; invasive plants; knotweed; polyphenolics



Polyphenol complexes from Reynoutria and their potential benefits

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LINOLEUM FOR MCCA RECOVERY FROM FERMENTATION BROTH

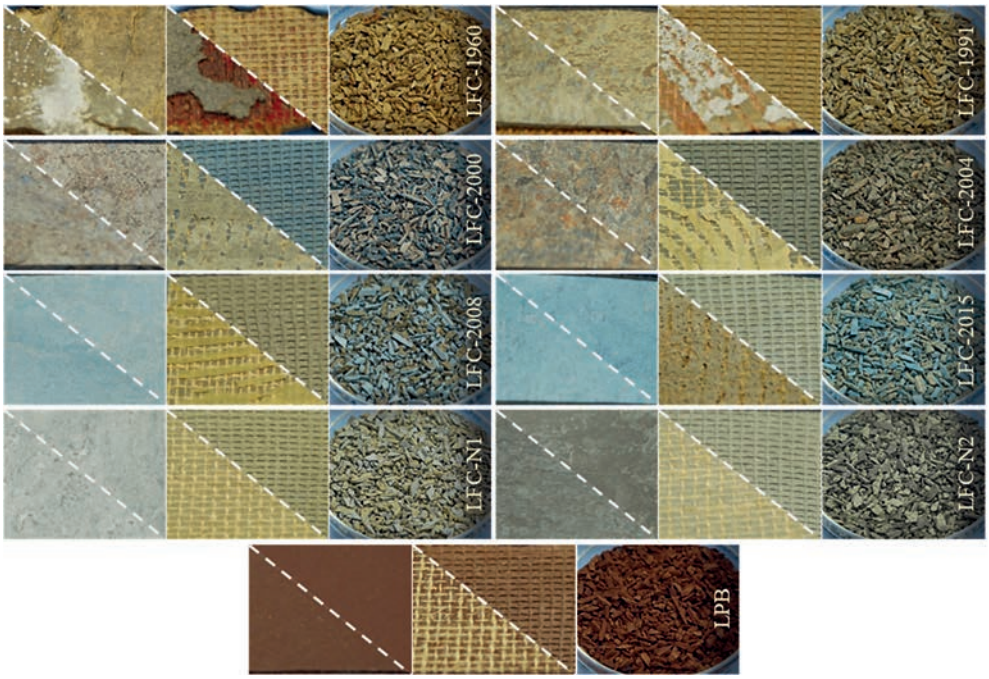
Patrick BRANDES[1]*, Iris STEINBERG[2]

[1,2] *Darmstadt University of Applied Sciences, Department of Civil and Environmental Engineering, 64295 Darmstadt, Germany*

* ***Corresponding author.*** *Email address: patrick.brandes@h-da.de*

Abstract – The fermentative production of medium-chain carboxylic acids (MCCAs) from biogenic residues and waste streams offers the opportunity to further exploit the potential of corresponding biomass, which remains only partly utilized to date, even in countries with advanced waste management systems. One of the most critical challenges within the process, also known as 'carboxylate platform', is product recovery. Currently used separation methods for the recovery of MCCAs produced by anaerobic fermentation, such as solvent extraction, adsorption with ion-exchange resins, membrane processes, distillation or precipitation lead to high energy consumptions, high operating/investment costs, the formation of significant additional waste streams and/or low recovery rates. This study examines an alternative potentially economically and environmentally viable separation method, the recovery of MCCAs from an aqueous solution by employing linoleum as an adsorbent. Within the scope of this study, six different linoleum waste samples with previous utilization as floor coverings for 10 to 65 years, two new floor coverings and unused linoleum printing block (intended for linocut printing) are examined and compared to heptane and rapeseed methyl ester as conventional solvents for MCCA recovery. Experiments are conducted at laboratory scale and examine two potential scenarios for the adsorption process within the carboxylate platform under different operating conditions. The first scenario is product recovery after fermentation is completed, under favorable conditions for recovery. For this application pH is set to 3.0 and experiments are conducted at room temperature. In the second scenario product recovery and fermentation take place simultaneously, operating conditions are therefore set to pH 5.7 and 35 °C to simulate respective (suboptimal) conditions. The experiments revealed that selective separation of MCCAs from an aqueous solution by linoleum and linoleum waste is possible. Achieved separation efficiencies as well as advantages and disadvantages largely align with those of conventional solvent extraction. The adsorption rates for the individual carboxylic acids increase with an increasing chain length of the acids and depend on the pH of the fermentation broth. The adsorption process generally works better at low pH (significantly below the pKa value of the corresponding acids). However, adsorption rates can also be optimized by increasing the surface area of linoleum or conducting several successive adsorption cycles. Furthermore, even after several decades of utilization as floor covering, the first life cycle does not appear to impair the adsorption properties through potential decomposition or chemical alteration of the organic compounds.

Keywords – Adsorption; carboxylate platform; carboxylic acid recovery; circular economy; medium-chain carboxylic acids; product recovery



Linoleum used as adsorbent, linoleum floor covering (LFC) and linoleum block print (LPB), top and bottom sides respectively before/after cleaning and crushed material

ACKNOWLEDGEMENT

The study was supported by the Research Centre for Sustainable Processes and Technologies of Darmstadt University of Applied Sciences, a member of EUt+.

The authors wish to express their gratitude to Henning Böckemeier-Beckmann (Darmstadt University of Applied Sciences, Department of Chemistry and Biotechnology) for valuable discussions on the chemical background of this study.

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MICROWAVE-ASSISTED HYDROTHERMAL CARBONIZATION OF SELECTED BIOMASSES WITH UREA

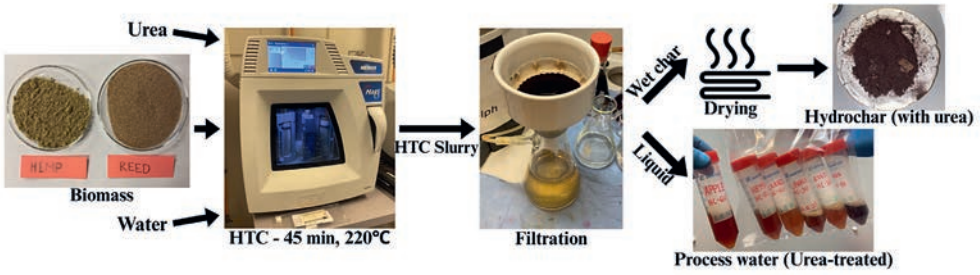
Rudolfs DREVINSKIS[1*], Taras MIKA[2], Valerija KOSTEVICA[3], Ilze VAMZA[4], Dagnija BLUMBERGA[5]

[1–5] *Institute of Energy Systems and Enviroment, Riga Technical University, Azenes iela 12-1, LV-1048, Riga, Latvia*

[*] ***Corresponding author.*** *Email address: Rudolfs.Drevinskis@edu.rtu.lv*

Abstract – The condition of Latvian agricultural land has been deteriorating over the years. More than a quarter of Latvian agricultural are acidic and require liming. 35 % of the studied agricultural lands have low phosphorus reserves and 24 % have low potassium levels. A possible solution to the problem of improving soil quality is the use of hydrochar. Doping of hydrochar by nitrogen introduces specific surface functional groups. This leads to increased surface reactivity, improved cation exchange capacity and affinity for nutrients and pollutants. As a soil additive, it will contribute to slow nitrogen release and increased nutrient use efficiency. It could be a cheap, environmentally friendly material that contributes to waste reduction and carbon storage, which is consistent with the principles of a circular economy and sustainable agriculture. Biomass samples with relatively higher N, P and K content were selected for the study: reed, hemp, leaves, apple pomace, Canadian goldenrod and brewery's spent grains. Urea was chosen as a model compound (one of the main components of animal wastes). Hydrothermal carbonization (HTC) was carried out at 220 °C for 45 min in closed Teflon containers in a MARS 6 microwave digestion system. Deionized water was used, as well as 10 % (wt.) urea solutions in a liquid: biomass ratio of 10:1 for HTC. ATR-FTIR spectroscopy revealed a decreased amount of (C=O)-containing functional groups (~1730 cm–1) in water-treated hydrochar up to their almost complete removal in urea-treated samples. Interaction between hydrochar and Cu2+ revealed no absorption at all. Absorption studies (UV-Vis spectrophotometry) of Methylene blue showed high removal efficiency (~96 %), but quiet low absorption capacity ~8 mg/g (at pH=7.4) with almost no significant differences between water- and urea-treated hydrochars. Finally, red-ox interaction between MnO4– and hydrochars shows that urea prevents oxidation of surface functional groups during HTC. As a result, final hydrochars have higher reduction properties what may significantly affect its behavior and shelf-life when used as soil amendment. Further studies are needed to understand short- and long-term effects on soil quality, as well as absorptions of pollutants in specific conditions, and evolution of C and N during its shelf life. However, obtained results show possibility of hydrochar production with regulated properties.

Keywords – Adsorption; carbon sequestration; nitrogen doping; soil amendment; sustainability



Hydrochar production scheme

ACKNOWLEDGEMENT

This work has been supported by The National Research Program of the Latvian Science Council "Decision-making Support System for Achieving Climate Neutrality Goals" Project no. VPP-KEM-Klimatneitralitāte-2023/1-0002.

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PHYSIOLOGICAL RESPONSE OF SWEET CORN (*Zea Mays L. var. Saccharata*) CULTIVAR ZEATON TO ORGANIC AND ORGANO-MINERAL FERTILIZATION

Violeta VALCHEVA[1], Kostadin KOSTADINOV[2], Nadezhda SHOPOVA[3], Radoslav CHIPILSKI[4]

[1,2] *Agricultural University – Plovdiv, AU, 12 Mendeleev Blvd, 4000, Plovdiv, Bulgaria*
[3] *Climate, Atmosphere and Water Research Institute at Bulgarian Academy of Sciences (CAWRI-BAS), 66 Blvd Tzarigradsko chausse, 1784, Sofia, Bulgaria*
[4] *Institute of Plant Genetic Resources, 2 Drouzhba Str., 4122 Sadovo, Plovdiv District, Bulgaria, Agricultural Academy, Sofia, Bulgaria*
* ***Corresponding author.*** *Email address: kostadinov8888@gmail.com*

Abstract – Sweet corn is highly sensitive to environmental conditions, particularly during the reproductive stage, when physiological stability is crucial for yield formation. Under increasing climate variability, nutrient management plays an important role in enhancing plant tolerance to abiotic stress. The aim of this study was to evaluate the physiological response of sweet corn cultivar Zeaton to organic and organo-mineral fertilization under the agro-climatic conditions of Plovdiv, Bulgaria. Field experiments were conducted during the 2024–2025 growing seasons at the Agricultural University of Plovdiv. Three treatments were compared: non-fertilized control, organo-mineral fertilization with Gold Forte, and organic fertilization with Triumfalis. Physiological parameters related to photosynthetic efficiency, chlorophyll content, and canopy temperature were assessed. Both fertilization treatments improved plant physiological status compared to the control. The organic fertilizer showed the strongest positive effect, indicating enhanced photosynthetic activity and improved thermal regulation under variable climatic conditions.

Keywords – Abiotic stress tolerance; canopy temperature; chlorophyll index; climate variability; field experiment; photosynthetic efficiency; plant nutrition

ACKNOWLEDGEMENT

This study was conducted with funding provided by the Center for Research, Intellectual Property Protection and Technology Transfer at the Agricultural University - Plovdiv.

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EFFECT OF ORGANIC AND ORGANO-MINERAL FERTILIZATION ON PRODUCTIVITY TRAITS OF SWEET CORN (*Zea mays L. var. saccharata*) CULTIVAR ZEATON

Kostadin KOSTADINOV[1], Nadezhda SHOPOVA[2], Radoslav CHIPILSKI[3]

[1] *Agricultural University - Plovdiv, AU, 12 Mendeleev Blvd, 4000, Plovdiv, Bulgaria*
[2] *Climate, Atmosphere and Water Research Institute at Bulgarian Academy of Sciences (CAWRI-BAS), 66 Blvd Tzarigradsko chausse, 1784, Sofia, Bulgaria*
[3] *Institute of Plant Genetic Resources, 2 Drouzhba Str., 4122 Sadovo, Plovdiv District, Bulgaria, Agricultural Academy, Sofia, Bulgaria*
* ***Corresponding author.*** *Email address: kostadinov8888@gmail.com*

Abstract – Sweet corn productivity is strongly influenced by nutrient availability and environmental conditions during the growing season. Optimizing fertilization strategies is essential for maintaining stable yield under climate stress. The objective of this study was to assess the effect of organic and organo-mineral fertilization on the productivity traits of sweet corn cultivar Zeaton grown in Plovdiv, Bulgaria. The experiment was carried out during 2024–2025 at the Agricultural University of Plovdiv and included three treatments: non-fertilized control, fertilization with the organo-mineral fertilizer Gold Forte, and fertilization with the organic fertilizer Triumfalis. Yield-related parameters were evaluated at consumer maturity. Both fertilization treatments significantly improved yield components compared to the control. Plants fertilized with organic fertilizer achieved the highest ear mass, kernel number, kernel weight per ear, and thousand-kernel weight, demonstrating superior productivity under the given agro-climatic conditions.

Keywords – Agro-climatic conditions; ear characteristics; field trial; kernel traits; nutrient management; yield stability; yield structure

ACKNOWLEDGEMENT

This study was conducted with funding provided by the Center for Research, Intellectual Property Protection and Technology Transfer at the Agricultural University - Plovdiv.

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UNDERSTANDING THE BIOMASS FLOWS AT THE LOCAL LEVEL

Anna KUBULE[1*], Dace LAUKA[2], Krista LAKTUKA[3], Ilze VAMZA[4], Dagnija BLUMBERGA[5]

[1–5] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia*

[*] ***Corresponding author.*** *Email address: anna.kubule@rtu.lv*

Abstract – While bioeconomy provides the opportunities for sustainable development, reducing fossil fuel dependence and improving local socio-economic conditions, previous assessments of the bioeconomy share of the whole economy in various countries is on average lower than 10 % (but also varying by the used methodology and sectors included in the assessment). Bioeconomy development is limited due to numerous factors, including, bioresource availability, knowledge and infrastructure for high added value biotechnology production and even local social acceptance of new bioeconomy business models and changing of the accepted practices. Local level assessment is important for understanding of biomass flows, supply and demand tendencies. To enhance bioeconomy development, better knowledge of biomass production and use on the resource supply side, as well as of the demand for bioproducts, must be obtained. To enhance bioeconomy development, better knowledge of the production and use of biomass at the resource supply side, as well as the demand of bioproducts must be obtained. The aim of this research is to gain better understanding of the biomass flows (including forestry, agriculture, aquaculture and industrial by-products) at the local municipality level. Although there are methodologies for biomass flow analysis and bioeconomy assessment at the national level, the transferring of those methodologies to the local level are commonly hindered by lack of data in the necessary level of detail. This study includes identifying the location dependent information sources on biomass availability and bioproduct production tendencies and elaborating a data sourcing methodology for biomass flow accounting. Considering the nature of sustainable development (SD) concept, all three dimensions of SD are analysed – environmental, economic and social aspects. The results of this analysis are being further used to elaborate a local level bioeconomy ecosystem model to further promote bioeconomy development.

Keywords – Bioeconomy; biomass availability; bioresource potential; sustainable development

ACKNOWLEDGEMENT

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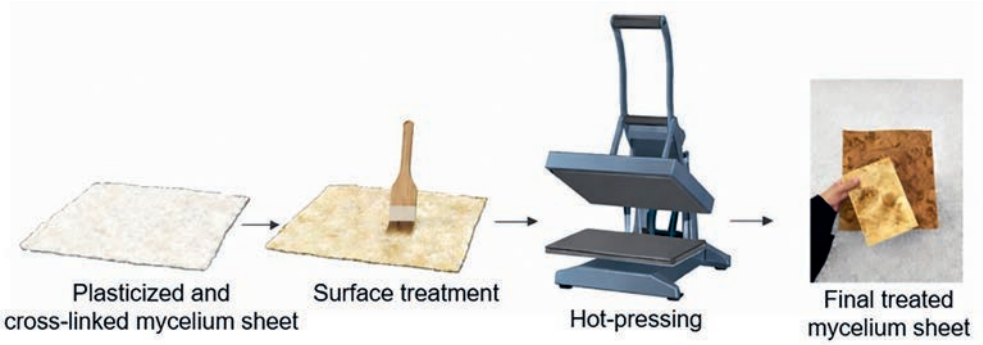
BIO-BASED SURFACE COATING AND POST-PROCESSING OF *Trametes Versicolor* MYCELIUM-BASED LEATHER-LIKE MATERIALS

Beatrice BENETTI[1], Fosca CONTI[2*], Simon VANDELOOK[3], Eveline PEETERS[4]

[1] *Department of Biology, University of Padova, Via U. Bassi 58/B, 35131 Padova, Italy*
[2] *Department of Chemical Sciences, University of Padova, via Marzolo 1, 35131 Padova, Italy*
[3,4] *Department of Bioengineering Sciences, Vrije University of Brussels, 1050 Brussels, Belgium*
[*] ***Corresponding author.*** *Email address: fosca.conti@unipd.it*

Abstract – The textile and fashion industry is one of the most polluting sectors worldwide, contributing significantly to greenhouse gas emissions and water contamination. Conventional leather tanning is a non-sustainable process that consumes large amounts of water and energy, while releasing heavy metals and toxic compounds into the environment. Although synthetic leather simplifies production, it relies on fossil-derived polymers and is non-biodegradable, raising additional environmental concerns. Filamentous fungi, with their capacity to form leather-like biomaterials through controlled fermentation, represent a promising and sustainable alternative. Mycelium-based materials are emerging as promising bio-derived alternatives to animal and synthetic leather. However, mechanical strength and surface properties remain limiting for commercial applications. This study investigates bio-based post-processing strategies for *Trametes versicolor* mycelium-based leather-like materials produced via liquid-state surface fermentation. Primary focus was on surface functionalization through natural coatings. Hot pressing was first evaluated and then adopted as a standard treatment. Indeed, the ultimate stress of glycerol-treated sheets was increased from 0.31 ± 0.06 to 0.45 ± 0.06 MPa, confirming the suitability of hot processing as a standard consolidation step. Subsequently, sorbitol–citric acid treated mats were coated with seven fully bio-based formulations, including proteins, polysaccharides, shellac, and wax–oil blends, and evaluated through static water contact angle (WCA) measurements. The uncoated control mat exhibited the highest hydrophobicity with WCA of 99.8°, while coated samples showed WCAs ranging from 65.1° (corn zein) to 95.3° (wax–oil balm). Some process steps are presented in the figure. Coatings rich in hydrophobic long-chain molecules yielded the best water repellence properties, whereas protein- and polysaccharide-based films primarily altered surface texture without enhancing wettability. The results highlight the importance of chemical formulation – particularly plasticizer content – in determining surface hydrophobicity, and provide a foundation for the development of scalable, fully bio-based surface finishing treatments for fungal leather-like materials.

Keywords – Biofabrication; biomaterials; fungal-leather; fungal biotechnology; liquid-state surface fermentation; mimco-leather, non-leather materials; sustainability; sustainable fashion



Key process steps to obtain Trametes Versicolor mycelium-based leather-like sheets

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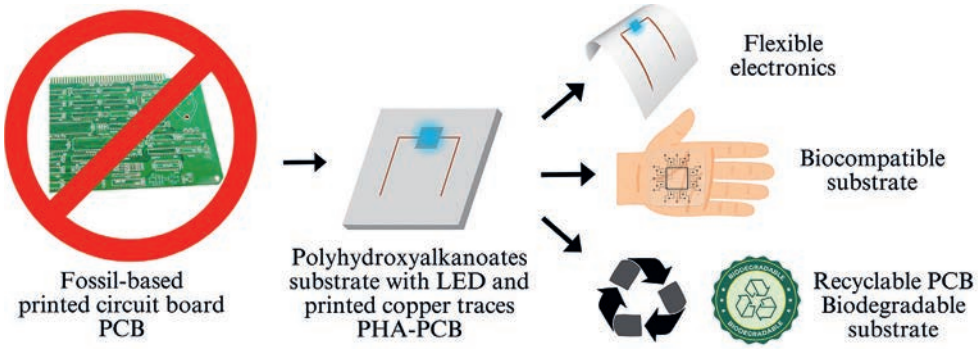
POLYHYDROXYALKANOATES FOR BIODEGRADABLE PRINTED CIRCUIT BOARDS FOR BIO-MICROELECTRONICS

Gabriele RIGATO[1], Nihesh MOHAN[2], Gordon ELGER[3], Lorenzo FAVARO[4], Ameya Pankaj GUPTE[5], Fosca CONTI[6*]

[1] *Department of Biology, University of Padova, Via U. Bassi 58/B, 35121 Padova, Italy*
[2,3,5] *Institute for Innovative Mobility, Technische Hochschule Ingolstadt, Esplanade 10, 85049 Ingolstadt, Germany*
[4,5] *Department of Agronomy Food Natural Resources Animals and Environment, University of Padova, Viale dell'Università 16, 35020 Legnaro, Italy*
[4] *Department of Microbiology, Stellenbosch University, Private Bag X1, 7599 Stellenbosch, South Africa*
[6] *Department of Chemical Sciences, University of Padova, Via Marzolo 1, 35131 Padova, Italy*
[*] ***Corresponding author.*** *Email address: fosca.conti@unipd.it*

Abstract – Printed circuit boards (PCBs) are essential components of nearly all electronic products and consist of laminated structures combining conductive and insulating layers. Conventional PCB manufacturing relies on fossil-based and poorly degradable materials, with FR-4 – composed of woven fiberglass reinforced epoxy resin – being the most widely used substrate. When improperly managed at the end-of-life stage, PCBs pose significant environmental and health risks. Current disposal practices, including incineration and e-waste storage, contribute to the release of carcinogenic and persistent pollutants such as dioxins and polycyclic aromatic hydrocarbons, with severe impacts on ecosystems and human health. Consequently, there is an urgent need to develop simplified recycling strategies and to adopt environmentally friendly materials for both substrates and processing reagents. Polyhydroxyalkanoates (PHAs) represent a promising class of biopolymers synthesized by microorganisms. PHAs combine functional performance with intrinsic biodegradability and enable controlled degradations of electronic substrates after disposal. In this work, PHAs are investigated as sustainable PCB substrate materials, processed through additive manufacturing techniques such as drop casting, spray coating, inkjet printing, and laser activation to support material-efficient and low-impact fabrication routes. The research is presented in the scheme. The surface morphology and topography of the surface of the new substrates are characterized using optical profilometry. while cross-section analyses and scanning electron microscopy (SEM) are employed to evaluate layer integrity, microstructure, and interfacial quality. Thermal properties are evaluated by thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC), while physiochemical behaviour is assessed through viscosity measurements to determine processability for printing-based techniques. Mechanical performances are investigated via strength tests. In addition, eco-friendly solvent-based approaches are explored for the recovery and recycling of materials, aiming to close the material loop and enhance circularity. Overall, the integration of biodegradable polymers, advanced manufacturing techniques, comprehensive material characterization, and green recycling strategies suggest viable pathways toward environmentally responsible microelectronics and support the transition to a more sustainable future for electronic materials.

Keywords – Additive manufacturing; alternative biomaterials; biodegradable polymers; bioplastics; bioresources; bio-substrates; e-waste management; microelectronics; sustainable electronics



Scheme of the current research to replace fossil-based PCBs with biodegradable substrates

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LIFE CYCLE ASSESSMENT OF INNOVATIVE REED BIOMASS PRODUCTS

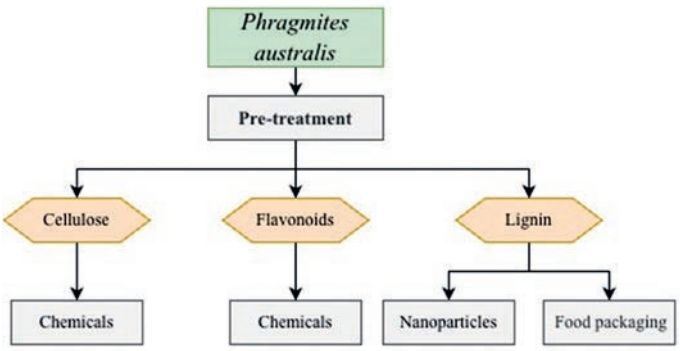
Artis JAUNKĻAVIŅŠ[1*], Francesco ROMAGNOLI[2], Maksims FEOFILOVS[3]

[1–3] *Riga Technical University, Faculty of Natural Sciences and Technology, Azenes iela 12/1, Riga, LV-1048, Latvia*

[*] ***Corresponding author.*** *Email address: artis.jaunklavins@edu.rtu.lv*

Abstract – In Latvia, the common reed (*Phragmites australis*) is widespread in wetlands and mainly considered as a nuisance due to its rapid spread, a large amount of this biomass is available across wetlands, which has not been sufficiently explored as a renewable bioresource. Given the high availability of underutilized *P. australis* biomass and its current perception as a low-value or problematic resource, there is a clear need to explore sustainable and value-added utilization options and to assess their potential environmental impacts. The aim of the study is to identify innovative biomass utilization pathways and products derived from *P. australis* and compare their environmental performance by conducting a life cycle assessment (LCA). The LCA methodology in the study complies with the International Standard ISO 14040-44. SimaPro 10.2 software was used for data analysis and modelling. The functional unit is defined as the consumption of 1 ton of *P. australis* raw materials for production. This functional unit was chosen because it allows comparison of the final product with other alternative materials from *P. australis*. Data for *P. australis* biomass products were obtained from scientific literature, thereby ensuring the study's reliability, which directly depends on the quality of data. *P. australis* product modules were developed based on the cradle-to-gate approach principle. In the growth stage of *P. australis*, no additional agricultural work and fertilizers are required, and infrastructure related to harvesting and production facilities is not included in the system boundaries. The product use and end-of-life stages were not included in the analysis. The study conducted an LCA and identified primary and secondary products from *P. australis*, such as flavonoids, cellulose, hemicellulose, and lignin, which can be converted into high-value-added chemical products. These include lignin-based polyols, lignin nanoparticles, and indole- and flavonoid-based chemical compounds, thus providing raw materials for the industrial production of food packaging and pharmaceutical products. This study is essential because it opens opportunities to develop biorefinery facilities in Latvia from potentially widely available, unused resources, which would support the region's development.

Keywords – Bioeconomy; flavonoids; indole; lignin; nanoparticles; phragmites australis



Simplified scheme of chemicals and materials derived from *P. australis*

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INSIGHTS INTO PRETREATMENT METHODS FOR BREWERS' SPENT GRAIN VALORIZATION AS A MICROBIAL SUBSTRATE

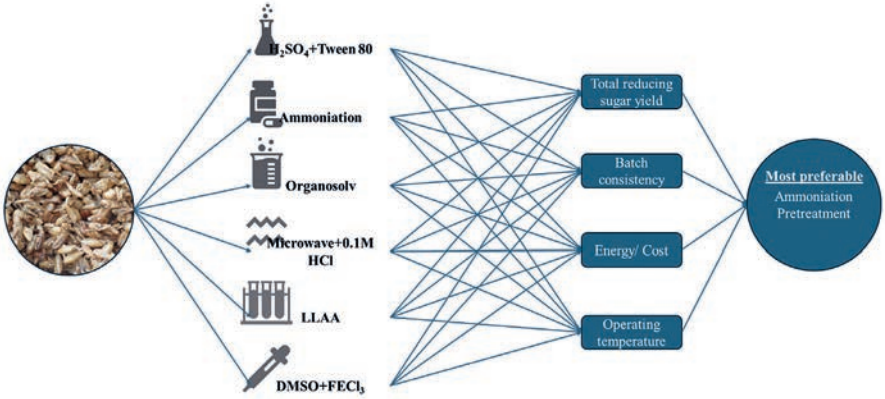
Kushan AKURATIYA[1*], Taras MIKA[2], Ilze VAMŽA[3]

[1–3] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia*

[*] ***Corresponding author**. Email address: kushan.akuratia@rtu.lv*

Abstract – Brewers spent grain (BSG), the primary byproduct of the brewing industry has significant potential due to its rich nutrient content, and numerous studies are being conducted on its valorization. Despite the research conducted, enormous quantities of BSG are still disposed of in landfills, causing environmental issues. Researchers have identified that BSG contains the nutritional requirements for growing distinct types of microorganisms; however, due to the high lignin content and complex chemical nature of BSG, assimilation of these nutrients is restricted. Therefore, this study aimed to identify the most suitable pretreatment method for BSG to extract nutrients to obtain a commercially viable, optimal substrate for microorganism cultivation. Six pretreatment methods and their optimal conditions were selected from previous research on BSG and similar lignocellulose biomasses. The pretreatments resulted with average total reducing sugar yields (TRS) as: dilute sulfuric with Tween 80 pretreatment (82.03 mg/g BSG), Ammoniation pretreatment (169.79 mg/g BSG), aqueous ethanol organosolv pretreatment (166.03 mg/g BSG), microwave assisted hydrochloric pretreatment (320.4 mg/g BSG), low liquid aqueous ammonia pretreatment (145.3 mg/g BSG) and ferric (III) catalyzed dimethyl sulfoxide pretreatment (236.81 mg/g BSG). A TOPSIS assessment based on TRS, batch consistency, cost, energy consumption and operating temperature identified Ammoniation pretreatment as the most suitable method for nutrient extraction from BSG to create a commercially viable substrate for microorganism cultivation.

Keywords – Batch consistency; chemical cost; energy consumption; operating temperature; total reducing sugar yield



Evaluation framework for assessing BSG pretreatment methods

ACKNOWLEDGEMENT

This research was funded by the Fundamental and Applied Research Project 'Herbicides as a tool for selection of edible protein-rich mutants,' project No. lzp-2022/1-0126, funded by the Latvian Council of Science.

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OPTIMIZATION OF *Phaffia Rhodozyma* SINGLE-CELL PROTEIN PRODUCTION BY RESPONSE SURFACE METHODOLOGY

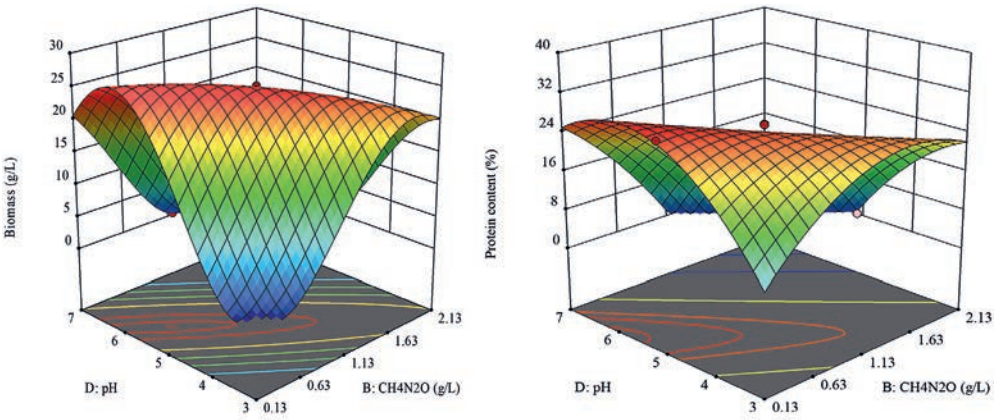
Zane KUSNERE[1*], Svetlana RAITA[2], Iveta KUZMIKA[3], Zane GEIBA[4], Taras MIKA[5], Karlis VALTERS[6]

[1–6] *Riga Technical University, Institute of Energy Systems and Environment, Azenes iela 12/1, Riga, Latvia*

[*] ***Corresponding author.*** *Email address: zane.kusnere@rtu.lv*

Abstract – *Phaffia rhodozyma* is widely used as a natural source of astaxanthin for aquaculture, but its protein-rich biomass remains underexplored as single-cell protein (SCP). This study aimed to reposition *P. rhodozyma* as a dual-output platform by optimizing a low-cost medium for a protein-enhanced mutant (AEC3/9) while tracking astaxanthin formation. A central composite design/response surface methodology evaluated glycerol, urea, ammonium sulfate and initial pH. Triplicate shake-flask cultivations (250 mL baffled flasks, 20 mL working volume, 22 °C, 250 rpm, 7 d) showed that protein productivity peaked on day 4, which was used as the reference timepoint for optimization; astaxanthin was modeled but not set as an optimization target. Numerical desirability indicated moderate glycerol (70–90 g/L), low urea (<0.2 g/L) and slightly acidic pH (~5.9) as favorable. The selected optimum (70.54 g/L glycerol, 0.134 g/L urea, 4.98 g/L $(NH_4)_2SO_4$, pH 5.86) yielded 26.11 g/L biomass with 29.79 % protein (7.78 g/L). Scale-up in a 5 L stirred-tank bioreactor con-firmed feasibility, reaching 33.50 g/L biomass and 6.82 g/L protein at 88 h, and indicating that protein accumulation precedes the astaxanthin-associated phase transition. Optimizing nitrogen form/level and pH enables robust production of *P. rhodozyma* biomass on glycerol, supporting its use as a scalable SCP co-product alongside astaxanthin.

Keywords – Astaxanthin co-production; effective substrate conversion; fermentation optimization; scale-up; single-cell protein



The three-dimension response surface plots demonstrated the influence of the interaction between the two independent variables on biomass (a) and protein content (b)

ACKNOWLEDGEMENT

This work was supported by the Fundamental and Applied Research Project "Herbicides as a tool for selection of edible protein-rich mutants", project No. lzp-2022/1-0126, funded by the Latvian Council of Science.

04

RENEWABLE ENERGY TECHNOLOGIES

https://doi.org/10.7250/CONECT.2026.057

MCFC AS ELECTROCHEMICAL DEVICES FOR CO_2 CAPTURE AND PRODUCTION OF SYNTHETIC FUELS

Karolina MAJEWSKA*

Institute of Heat Engineering, Warsaw University of Technology, 21/25 Nowowiejska Street, Warsaw 00-665, Poland

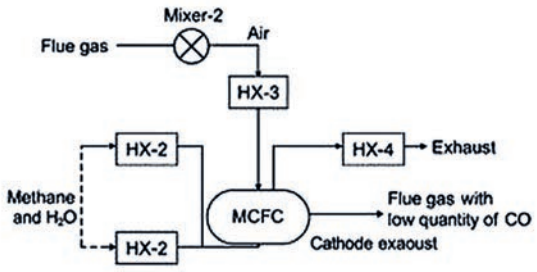
* ***Corresponding author.*** *Email address: karolina.majewska3.dokt@pw.edu.pl*

Abstract – Molten Carbonate Fuel Cells (MCFCs) enable simultaneous electrochemical CO_2 capture and power generation by selectively extracting CO_2 from flue gases at high temperature. This study analyses the integration of an MCFC downstream of a coal-fired power plant, treating the system as both a decarbonization unit and a CO_2 concentration platform for synthetic fuel production. System-level modelling shows that MCFC integration can reduce net CO_2 emissions by up to 56 % (288 kg CO_2/MWh) while increasing total electrical power output, demonstrating the potential of MCFCs as a bridging technology between carbon capture and Power-to-Fuels systems.

Separating CO_2 from flue gases using a molten carbonate fuel cell

The Molten Carbonate Fuel Cell (MCFC) can simultaneously capture CO_2 from flue gas and increase total power generation due to its high electrical efficiency. In the analysed system, MCFC operation is optimized with respect to power generation efficiency while enabling electrochemical CO_2 separation. Fuel cell efficiency is defined on a higher heating value basis. Because coal-fired flue gas contains insufficient oxygen, additional air is supplied to achieve a CO_2/O_2 molar ratio of approximately 2.0. The system configuration, shown in figure, integrates the MCFC stack with four heat exchangers to recover heat from fuel, steam, and flue gas streams. Optimization variables include fuel flow rate, current density, heat exchanger effectiveness, and air addition, subject to constraints on maximum stack temperature (650 °C), positive cell voltage, and a minimum steam-to carbon ratio of 1.4. CO_2 removal is quantified based on the reduction of CO_2 mass flow at the cathode. The results show that the MCFC produces 2.7–3.2 kW per $Nm^3 \cdot s^{-1}$ of flue gas, increases total plant power output by about 50%, and achieves fuel cell efficiencies of 37–41 %. Depending on the optimization target, CO_2 emission reduction reaches up to 70 %, confirming the suitability of MCFC technology for efficient CO_2 capture in existing fossil-fuel-based power plants.

Keywords – Carbon capture and utilization (CCU); coal-fired power plant decarbonization; electrochemical CO_2 capture; flue gas decarbonization; high-temperature electrochemical systems; integrated energy systems; Molten Carbonate Fuel Cells (MCFC); Power-to-Fuels; CO_2 separation; synthetic fuel production



Schematic diagram of the MCFC-based system integrating four heat exchangers (HX-1 to HX-4), a flue gas-air mixer (Mixer-2), and the MCFC stack. Flows of fuel, steam and flue gas are highlighted to illustrate process integration and heat recovery

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DETERMINATION OF BIOFUEL CALORIFIC VALUE WITH MEASUREMENT UNCERTAINTY ESTIMATION

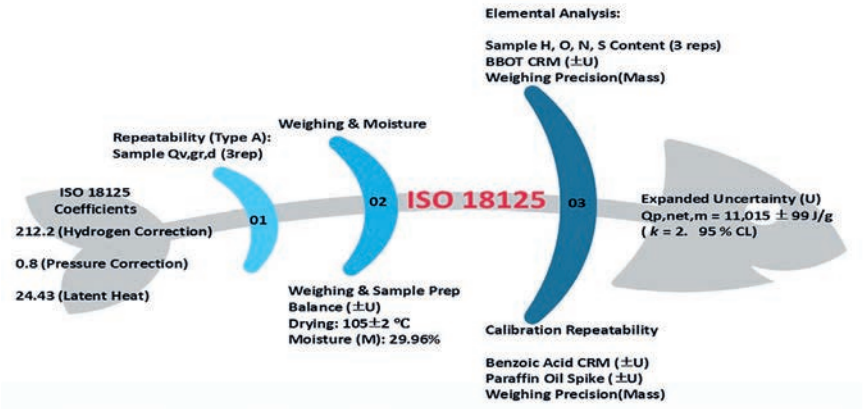
Youngje WOO[1*], Jungwon Ha[2], Kyeongok Kang[3]

[1–3] *K-eco (Korea Environment Corporation), 410, Jeongseojin-ro, Seo-gu, Incheon, Republic of Korea*

[*] ***Corresponding author.*** *Email address: safetyyj@keco.or.kr*

Abstract – This work was conducted as part of the official quality inspection of wood based BioSRF in accordance with the Resources Recycling Act of the Republic of Korea. The primary objective was to verify the precision of calorific value measurements, which is a critical parameter for solid recovery fuels. The gross calorific value was measured using an automatic bomb calorimeter following ISO 18125. Subsequently, the measurement uncertainty was estimated in accordance with the ISO/IEC Guide 98-3, also known as GUM, to provide a quantitative assessment of the analytical precision. For the analysis, the Bio-SRF wood pellets were pulverized into a sawdust form. This preparation step was conducted to ensure the sample was suitable for the combustion crucible and to facilitate precise calorific value measurements. The net calorific value at constant pressure was determined to be 11 015.26 Joules per gram. To achieve complete combustion, a paraffin oil spike was applied to thoroughly wet the porous structure of the sawdust samples. Due to the high surface area and volumetric characteristics of the sawdust, the mass of the paraffin oil spike exceeded that of the sample to ensure sufficient wetting. Despite this high spike to sample ratio, it was an essential procedure to achieve total energy release and complete combustion. According to ISO 18125, the repeatability limit for wood sawdust is specified as 120 Joules per gram. In this work, the difference between the individual determinations remained well below this standard. Furthermore, the estimated expanded uncertainty was plus or minus 98.76 Joules per gram with a coverage factor k equal to 2, which also falls within the 120 Joules per gram threshold. These results confirm that the analysis maintains a high level of precision consistent with international standards.

Keywords – Combustion aid (Benzoic acid); ISO 18125; quality inspection; repeatability limit



Ishikawa(fishbone) diagrams: A Measurement Uncertainty Estimation

ACKNOWLEDGEMENT

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ASSESSMENT OF GLARE/GLINT FROM PHOTOVOLTAIC SYSTEM NEAR TRANSPORT INFRASTRUCTURES

Rıdvan ÇELIK[1], Duygu KUZYAKA[2], Sreenath SUKUMARAN[3*], Sudhakar KUMARASAMY[4]

[1] *METU WindCenter for Wind Energy, Department of Aerospace Engineering, Middle East Technical University, 06800, Ankara, Türkiye*
[1,2] *Center for Solar Energy Research and Applications (GÜNAM), METU, Ankara, 06800, Türkiye*
[3] *Department of Energy Technology, Tallinn University of Technology, Tallinn, 19086, Estonia*
[4] *Centre for Automotive Engineering, Universiti Malaysia Pahang Al-Sultan Abdullah, Pekan, 26600, Malaysia*
[4] *Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, Pekan, 26600, Malaysia*
[4] *Energy Centre, Maulana Azad National Institute of Technology, Bhopal 462003, India*
[*] ***Corresponding author.*** *Email address: sreenath.sukumaran@taltech.ee*

Abstract – Installation of solar photovoltaic (PV) systems in built areas pose challenges in balancing renewable energy use with safety concerns. The aim of the study is to assess the glare/glint associated with a hypothetical solar power plant in the Mardin region in Türkiye, which offers favorable solar potential and is situated near key transportation infrastructures. The methodology involved analysis of eight PV configurations across three installation types with due consideration to anti-glare measures such as anti-reflective coatings and glass texture. Using industry-compliant *ForgeSolar* software, the duration and intensity of glare were obtained from multiple observer viewpoints, including air traffic control, flight paths, roadways, and police checkpoints. The analysis underscores significant aviation safety concerns, indicating that specific PV configurations may disrupt flight operations and visibility. The configuration featuring single-axis tracking with AR-coated glass – was identified as optimal. It achieved an annual energy production of 183 GWh, the highest among all configurations. The associated glare duration was limited to 185.5 hours per year of green-level glare, with no yellow-level glare observed, thereby remaining fully compliant with safety thresholds. This scenario also demonstrated approximately 18 % cost reduction compared to dual axis tracking alternatives. Seasonal glare patterns are observed for police checkpoints, particularly during spring and late summer. The findings revealed that optimal PV design in sensitive regions requires a balance between maximizing energy yield and minimizing glare impact. This research provides a framework for solar development near critical infrastructures in built environment, by adopting optimal combination of panel orientation, tracking technologies, and anti-glare measures. This work lays the groundwork for policy development and offers practical insights for solar developers, airport operators, and regulators navigating the complexities of renewable energy and transportation safety.

Keywords – Airport; aviation safety; reflectivity; roadways; solar energy

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ASSESSMENT OF AIR POLLUTION POTENTIAL FROM NON-TRADITIONAL BIOMASS FUELS

Jana CERNEJA[1*], Vivita PRIEDNIECE[2], Vladimirs KIRSANOVS[3]

[1–3] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, LV-1048 Riga, Latvia*

[*] ***Corresponding author.*** *Email address: jana.cerneja@rtu.lv*

Abstract – The United Nations Sustainable Development Goal (SDG) 7, on affordable and clean energy, aims to reduce the use of fossil fuels. In accordance with Directive 2023/2413 on the promotion of Renewable energy sources (RES), the European Union's 2030 target for renewable energy has been increased from 32 % to 42.5 %, with the intention of raising it to 45 %. This has led to a growing use of local resources, especially wood, thereby raising concerns about forest degradation and prompting a search for alternatives. The common reed (*Phragmites australis*), characterized by high biomass productivity and low management costs, is a widely available yet underutilized resource with significant potential for thermal energy production. The study focuses on analyzing the quality parameters of the reed pellets and the emissions produced during the combustion process. Additionally, ADMS-Screen was used to model quasi-Gaussian emission dispersion. The findings indicate that common reed pellets can partially substitute wood biomass, as the ENplus® classification requirements were met for pellets containing 60 % and 80 % reed, mixed with 40 % and 20 % wood, respectively. The produced emissions during the combustion process of both optimal proportions are higher than those of wood pellets. Although an emission control system can reduce these emissions to some extent, a comprehensive cost analysis is required to evaluate overall efficiency.

Keywords – Alternative; bioenergy; biomass pellets; combustion emissions; common reed (Phragmites australis); modelling

Methodological framework for the alternative biomass study

ACKNOWLEDGEMENT

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RISK ASSESSMENT FRAMEWORKS FOR INTEGRATING RENEWABLE ENERGY TECHNOLOGIES INTO EXISTING INFRASTRUCTURE: A STRUCTURED REVIEW

Andrew Safwat Ragheb SALEEB[1*], Jonas ŠAPARAUSKAS[2]

[1,2] *Department of Construction Management and Real Estate, Vilnius Gediminas Technical University, Sauletekio al. 11, Vilnius Lithuania*

[*] ***Corresponding author.*** *E-mail address: Andrew.Saleeb@vilniustech.lt*

Abstract – The rapid expansion of inverter-based renewables is transforming power, industrial and building infrastructures that were designed around centralized synchronous plants, creating new and interconnected risk profiles. This review synthesizes 2019–2025 academic and institutional literature to (i) classify the main technical, economic, operational and institutional risks associated with integrating renewables into existing infrastructure and (ii) evaluate quantitative and qualitative methods used to assess them. The synthesis shows that deterministic planning tools are inadequate under high renewable penetration. Probabilistic methods (Monte Carlo and probabilistic power flow) more accurately capture frequency, voltage and congestion risk distributions and can significantly reduce expected loss-of-load and energy-not-served metrics when embedded in planning studies. Multi-criteria decision analysis, particularly AHP- and TOPSIS-based approaches with fuzzy extensions, provides transparent ranking of technologies and integration strategies under conflicting technical, economic, environmental and social criteria, though results are sensitive to method choice and weighting. FMEA and fuzzy-FMEA effectively prioritize component-level failure modes in wind, PV and storage projects but are rarely linked to system-wide analyses. Emerging hybrid frameworks that couple probabilistic simulation, MCDA and (fuzzy) FMEA and align with ISO 31000 principles offer the most comprehensive coverage of the identified risk categories, yet their practical uptake is limited by data, modeling and governance gaps, especially for cybersecurity, climate resilience and social equity. The paper proposes an integrated risk taxonomy and outlines priorities for embedding such hybrid approaches into utility planning, project appraisal and energy-transition governance.

Keywords – Decision-support methods; Failure Mode and Effects Analysis (FMEA); Multi-Criteria Decision Analysis (MCDA); power-system resilience; probabilistic reliability modelling; uncertainty quantification

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OVERVIEW OF ENERGY FLEXIBILITY THROUGH DEMAND RESPONSE AND POWER-TO-X TECHNOLOGY

Ričards STIVRIŅŠ[1*], Agris KAMENDERS[2], Claudio ROCHAS[3]

[1–3] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia*

[*] ***Corresponding author.*** *Email address: ricards.stivrins@rtu.lv*

Abstract – The increasing penetration of renewable energy sources and sector coupling significantly raises demand for and the potential of energy system flexibility. Technologies, including demand-side flexibility, Power-to-X solutions, energy storage, and electrified heating, are increasingly recognized as key enablers for achieving climate neutrality while maintaining system reliability and economic efficiency. However, despite significant technological progress, there remains a lack of empirical research that integrates real-time operational data, market signals, and user-related parameters to assess the practical flexibility potential of buildings and industrial systems. This study aims to provide a scoping review of demand-side flexibility and sector coupling technologies in supporting renewable energy integration and improving overall energy system efficiency. Attention is given to demand response harnessing technologies such as heat pumps and Power-to-X applications through hydrogen production with electrolysis and energy storage systems, which can absorb excess renewable electricity and provide balancing services to the power system. The methodological approach scoping review of energy flexible technology with the development of a conceptual framework for future energy flexibility evaluation. The proposed framework integrates real-time energy consumption data, indoor comfort parameters, and electricity market signals to identify opportunities for demand response and optimal system operation. In addition, the study examines the potential role of digital technologies, including data analytics and smart energy management systems, in enabling more responsive and efficient energy use. The results of the proposed research framework could highlight that sector coupling, and flexible demand can significantly enhance renewable energy utilization, reduce system costs, and decrease greenhouse gas emissions. Furthermore, the integration of market signals and digital monitoring tools can unlock additional flexibility from buildings and industrial processes.

Keywords – Demand response technologies; demand-side flexibility; flexible technologies; renewable energy storage

ACKNOWLEDGEMENT

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05

LOW CARBON DEVELOPMENT AND BIOECONOMY

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PROCESS EVALUATION FOR ELECTROLYZED SUSTAINABLE AVIATION FUEL (ESAF)

Agung CAHYONO[1], Wei-Cheng WANG[2*], Jhe-Kai LIN[3], Chanathip HONGKHAMDEE[4]

[1–4] *Department of Aeronautics and Astronautics, National Cheng Kung University, Tainan, Taiwan*
[*] ***Corresponding author.*** *Email address: wilsonwang@mail.ncku.edu.tw*

Abstract – Electrolyzed sustainable aviation fuel (eSAF) produced from captured carbon dioxide and renewable hydrogen is a promising pathway to decarbonize aviation, yet it remains electricity intensive and cost sensitive. This study develops a plant-wide Aspen Plus® process model integrating: (i) CO_2 capture and conditioning, (ii) alkaline water electrolysis for green H2 generation, and (iii) reverse water gas shift and Fischer Tropsch synthesis (RWGS-FTS) followed by product separation into eSAF and other hydrocarbon products, such as naphtha and renewable diesel. To improve system efficiency, FT tail gas is conditioned via water knock-out and hydrogen recovery prior to conversion in a proton exchange membrane fuel cell (PEMFC) to offset purchased electricity. A base-case eSAF capacity and ±30 % scale scenarios are evaluated to establish consistent mass, energy and carbon balances and to perform techno-economic analysis (TEA). The TEA framework estimates the minimum fuel selling price (MFSP) and quantifies dominant cost drivers of electricity, electrolyzer performance, and CO_2 capture energy, complemented by sensitivity analysis to identify the most influential parameters governing eSAF competitiveness.

Keywords – CO_2 utilization; fuel cell; sustainable aviation fuel; techno-economic analysis; water electrolysis

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BIOGENIC CARBON UTILIZATION POTENTIAL IN THE CENTRAL BALTIC VIA AGRICULTURAL BIO-CCU VALUE CHAINS

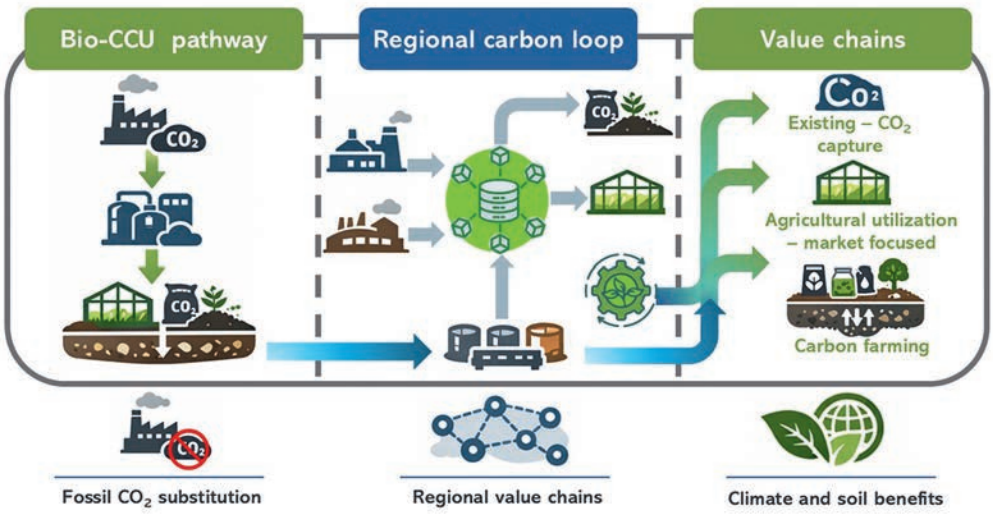
Lelde VISTARTE[1*], Jelena PUBULE[2], Anna KUBULE[3]

[1–3] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, Latvia*

[*] ***Corresponding author.*** *Email address: lelde.vistarte@edu.rtu.lv*

Abstract – Energy independence and resilience are closely tied to security and climate change mitigation. The European Union has set the goal of reducing GHG (greenhouse gas) emissions by at least 90 % by 2040 relative to 1990, and the development of the 2040 framework to achieve this aim has begun. To achieve this goal, reducing reliance on fossil fuels and switching to renewable energy sources are needed. The Renewable Energy Directive (RED) sets out binding targets for reaching 42.5 % or larger share of renewables in the energy mix by 2030. It will not be possible for the EU to reach climate neutrality by 2050, if all sectors do not rightly contribute to meeting this target. The agricultural sector in Latvia is still one of the most challenging sectors to reduce GHG emissions, ranking third after the energy sector (32.7 %) and transport (31.4 %), with 21.3 %. Carbon dioxide (CO_2), regardless of its origin, is used either as a product or an input material in various industrial applications. Globally, about 230 Mt CO_2 is emitted each year, with fossil CO_2 from natural gas reforming still dominating. Within the Central Baltic (CB) area, the use of CO_2 as an industrial gas largely depends on imported fossil fuels. The study aims to explore the potential of utilizing biogenic carbon (Bio-CCU) through regional agricultural Bio-CCU value chains and extend the CO_2 utilization into agriculture, a sector central to the CB region. Carbon farming can act as a demand-side pull for biogenic CO_2 utilization in agriculture, transforming waste CO_2 streams into verified carbon removals and promoting climate-smart farming practices.

Keywords – Bioeconomy; fossil carbon substitution; industrial symbiosis; regional value chains



Utilization of Bio-CCU via agriculture

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SUSTAINABLE AGRICULTURE PRODUCTS FROM THE SEA: ENVIRONMENTAL ASSESSMENT OF SEAWEED BASED FERTILIZER ENCAPSULATES IN NORTHERN EUROPE

Anna TRUBETSKAYA[1*], Monika VITVAROVA[2]

[1] *Faculty of Biosciences, Nord University, 7713 Steinkjer, Norway*
[2] *Devinn, Address, Skrivanci 4769/38, 466 01 Jablonec nad Nisou, Czech Republic*
[*] ***Corresponding author.*** *Email address: anna.trubetskaya@nord.no*

Abstract – The transition toward climate smart agriculture in Europe demands alternative renewable, low impact nutrient sources that can substitute current synthetic fertilizers. Seaweed represents a rapidly emerging marine biomass resource with strong potential for integration into biorefinery applications. This study presents a comprehensive environmental assessment based on Life Cycle Assessment (LCA) approach of solid biofertilizers produced from *Ascophyllum nodosum* cultivated in Norway and processed through a multi stage biorefinery system combining blanching, mechanical treatment, alginate extraction, ansaerobic fermentation, and final encapsulation in biodegradable matrices. Primary data collected from a Norwegian farm representing the 2025 production year were used to compile the life cycle inventory (LCI), while background data were obtained from the European Reference Life Cycle Database (ELCD) and the ecoinvent database. The life cycle assessment (LCA) was conducted in openLCA software following the methodological framework of the Product Environmental Footprint (PEF) 3.1 guidelines. The study adopted a cradle-to-gate system boundary, with the gate defined at the production of the encapsulated biofertilizer. Allocation between co-products was performed using a physical approach based on the mass fraction of valuable elements (nitrogen, N). In total, 22 environmental impact categories were quantified, including global warming potential, eutrophication, water use, cumulative energy demand, and mineral resource depletion. The results indicate that thermal processing operations—particularly hot-water blanching and warm extraction—constitute the dominant contributors to total energy consumption. Nevertheless, Norway's low-carbon electricity mix significantly mitigates the associated climate impacts, underlining the influence of regional energy systems and process design on life cycle-based environmental performance. Avoiding biomass drying, integrating biowaste valorization, and adopting greener solvents emerged as key optimization pathways. Encapsulation improved nutrient retention and supports controlled release application, aligning with precision agriculture goals. Overall, the study demonstrates that seaweed based encapsulated fertilizers can achieve markedly lower environmental burdens than many terrestrial fertilizer systems, if processing energy is sustainably sourced. These findings offer actionable insights for scaling marine based fertilizer production in Europe and guiding industrial biorefinery design toward circular, low emission agricultural inputs.

Keywords – Circular bioeconomy; controlled-release biofertilizers; encapsulation; LCA; seaweed biorefinery

ACKNOWLEDGEMENT

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MULTI-CRITERIA ANALYSIS FOR ASSESSING CARBON SEQUESTRATION PRACTICES IN AGRICULTURE UNDER THE EU CERTIFICATION SCHEME

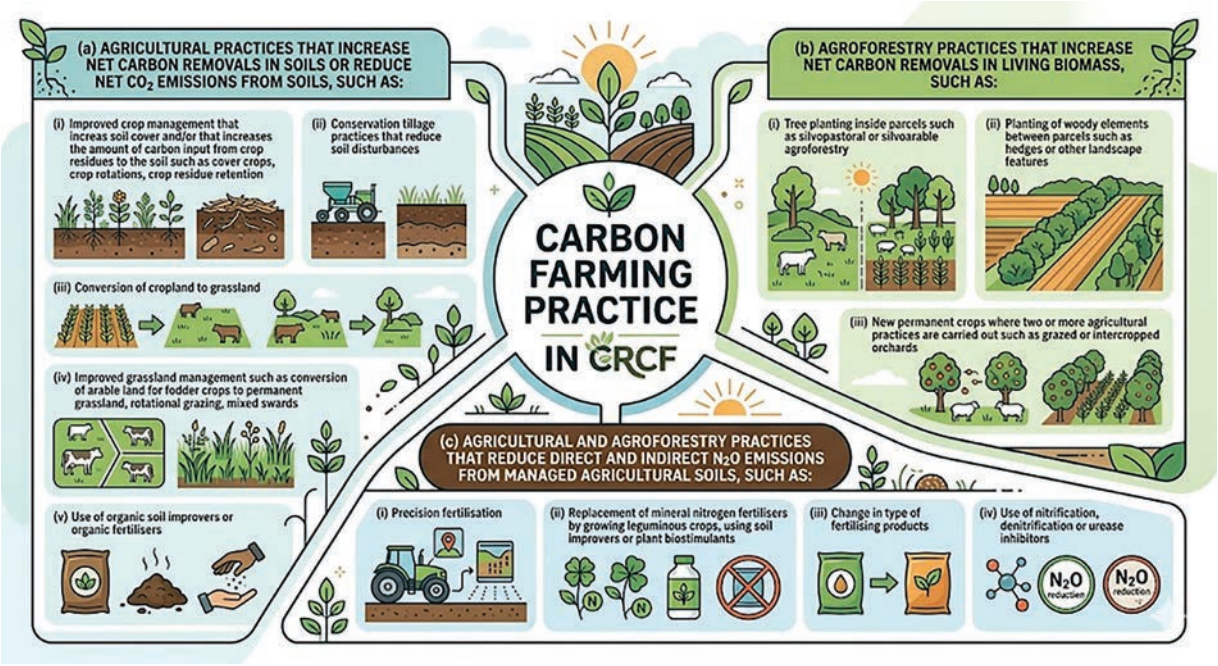
Ilze LUKSTA[1*], Krista LAKTUKA[2], Dagnija BLUMBERGA[3]

[1–3] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia*

[*] *Corresponding author. Email address: Ilze.Luksta@rtu.lv*

Abstract – The study focuses on the practical application of the European Union Carbon Certification Framework (CRCF) in agriculture. The aim of the work is to develop a framework that helps farmers and policymakers evaluate different carbon-related farming practices, such as agroforestry and soil improvement. The study uses multi-criteria analysis to evaluate practices not only according to their climate impact, but also according to their economic viability, implementation complexity and environmental co-benefits. The results offer a structured decision-making tool that facilitates the implementation of CRCF requirements on real farms, helping to identify the most suitable solutions for sustainable agriculture.

Keywords – Carbon farming; CRCF; European Union; TOPSIS.



Carbon farming practices

ACKNOWLEDGEMENT

This work has been supported by the Latvia's state budget Fundamental and Applied Research Project "A Policy Planning Roadmap for Carbon Farming Certification Schemes" No. lzp-2024/1-0417.

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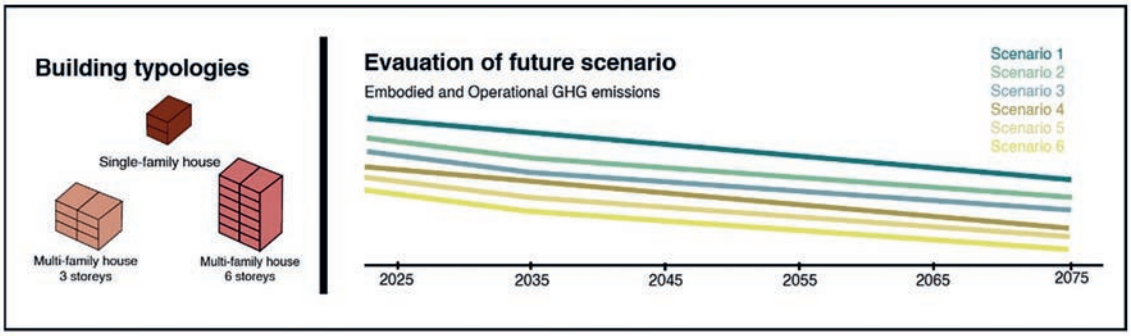
EVALUATING FUTURE EMBODIED AND OPERATIONAL CARBON EMISSIONS OF THE NEW BUILDING STOCK IN SPAIN

Bernardette SOUST-VEDAGUER[1*], Daniel CAGIGAS[2], Isidro CORTÉS[3], Rocío QUIÑONES[4], Alicia Isolina VÁZQUEZ[5], José Antonio GUTIERREZ MORENO[6], María Victoria MONTES[7], Luis Angel CASTRO[8], María Dolores FERNÁNDEZ GALVÉZ[9], Xabat OREGI[10], Elisabetta PALUMBO[11], Carmen LLATAS[12]

[1] *Departamento de Construcciones Arquitectónicas I, Universidad de Sevilla, Spain*
[2,5,8,12] *Departamento de Arquitectura y Tecnología de Computadores, Universidad de Sevilla, Spain*
[3,4,6,7,9] *Departamento de Construcciones Arquitectónicas II, Universidad de Sevilla, Spain*
[10] *Department of Architecture, University of the Basque Country, Spain*
[11] *Department of Engineering and Applied Sciences (DISA), University of Bergamo, Italy*
[*] ***Corresponding author.*** *Email address: bsoust@us.es*

Abstact – Given the urgent need to reduce CO_2 emissions from buildings and to anticipate future growth trends and their associated carbon footprint, this study explores potential future scenarios for new residential construction in Spain, with a specific focus on embodied and operational carbon emissions across the building life cycle. The research assesses how different development pathways could support the decarbonization of the building sector while accounting for environmental impacts and long-term sustainability goals. To achieve this, six different future scenarios have been developed using mathematical forecasting models, including linear regression, as well as official data on growing trends. These scenarios are subsequently assessed through a prospective Life Cycle Assessment (LCA), including modules A1–A5, B2, B4, B6, and C1–C4, to quantify their potential contribution to carbon-emission reduction. A Building Information Modelling (BIM)-based workflow is applied to estimate the environmental impact of new residential buildings, integrating official data on existing building typologies, geometric characteristics, and conventional materials and construction systems used in Span. The results identify scenarios that most effectively reduce both embodied and operational carbon emissions, underscoring the critical role of the development pathways and future trends in determining decarbonisation effectiveness. The study provides insights to support policymakers, planners, and industry stakeholders in defining evidence-based strategies for the decarbonization of residential construction in Spain.

Keywords – Building Information Modelling; construction materials; decarbonisation; future scenarios; prospective Life Cycle Assessment; residential buildings; Spain



DECIDE framework for evaluating 6 future scenarios for residential buildings in Spain

ACKNOWLEDGEMENT

The authors thank the funding organisation MCIN/AEI/10.13039/501100011033, the European Union "NextGenerationEU"/PRTR", FEDER, EU and the Consejería de Fomento, Articulación del Territorio y Vivienda, Junta de Andalucía for supporting the following projects: Grant US.24-04 and Grant PID2022-137650OB-I00.

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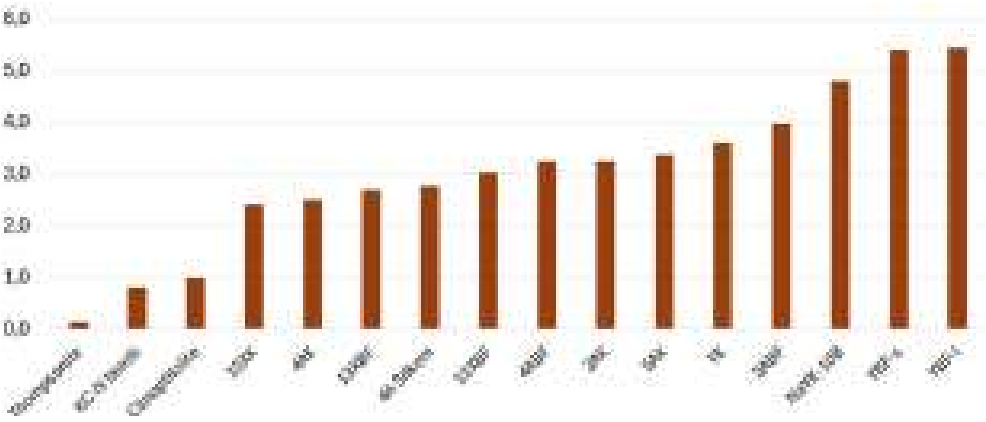
ZEOLITES FOR SELECTIVE CO_2 ADSORPTION

Bernhard ZETTL[1*], Gayaneh ISSAYAN[2]

[1,2] *University of Applied Sciences Upper Austria, Stelzhamerstrasse 26, 4600 Wels, Austria*
[*] ***Corresponding author.*** *Email address: Bernhard.zettl@fh-wels.at*

Abstract – This work investigates the selective CO_2 adsorption behaviour of various synthetic zeolites and provides a comparative assessment of their sorptive performance and regeneration characteristics under controlled conditions. CO_2 capture in zeolites plays an essential role in gas purification, sorption-enhanced reaction processes, and decentralized renewable energy systems, where efficient adsorption–desorption cycles directly impact process energy demand and operational stability. In this study, several zeolite types – including Faujasite-based materials (YBF, YK, 13XBF, 13XK) and LTA-type zeolites (4A, 5A, 3A) – were evaluated for their CO_2 uptake capacity under an applied pressure of 1 bar gauge (2 bar absolute). To ensure reproducibility, all samples were fully desorbed at 250 °C prior to CO_2 loading. The measured CO_2 adsorption capacities ranged from 2.5 to 5.4 mmol/g, with Faujasite-type zeolites exhibiting the highest uptake. The maximum capacity of 5.4 mmol/g, corresponding to approximately 25 wt% CO_2, was observed for binder-free Y-type zeolite (YBF). The preferred adsorption of water relative to CO_2 – rooted in the significantly higher dipole moment and adsorption enthalpy of H_2O – means that CO_2 adsorption is strongly affected by the hydration state of the zeolite. Consequently, complete removal of moisture is essential to achieving maximum CO_2 uptake. The experiments confirm that CO_2 remains in the gaseous state within the pores during adsorption due to its low critical temperature (31 °C), resulting in a lower reaction enthalpy compared to water and enabling rapid, low-energy desorption. Desorption studies demonstrate that CO_2 can be released either through exposure to ambient air, where water vapour displaces the adsorbed CO_2, or via controlled thermal treatment, which is more energy-efficient for subsequent reloading. Overall, the results highlight strong material-dependent differences in CO_2 capacity, fast and low-enthalpy regeneration behaviour, and the suitability of Faujasite-type zeolites – particularly binder-free variants – for cyclic CO_2 adsorption processes. The findings contribute to the optimization of zeolitic sorbents for gas-separation, methanation, and renewable energy applications, where rapid and energy-efficient CO_2 handling is essential.

Keywords – Gas adsorption; renewable gas purification; sorbent regeneration; zeolites



CO_2 adsorption in different sorptive materials contained within a pressurized vessel at 1 bar gauge pressure

ACKNOWLEDGEMENT

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FROM FRESH TO RIPENED CHEESE: LINKING ENERGY USE, ENVIRONMENTAL IMPACTS AND NUTRITIONAL VALUE IN A LIFE CYCLE PERSPECTIVE

Silvia CARDINI[1*], Anna SAVIO[2], Beatrice MARCHI[3], Simone ZANONI[4]

[1–3] *Department of Mechanical and Industrial Engineering, University of Brescia, Via Branze 38, 25123 Brescia, Italy*

[4] *Department of Civil, Environmental, Architectural Engineering and Mathematics, University of Brescia, Via Branze 43, 25123 Brescia, Italy*

[*] ***Corresponding author.*** *Email address: silvia.cardini@unibs.it*

Abstract –The dairy sector faces increasing pressure to reduce environmental impacts while maintaining nutritional quality and product diversity. Cheese production is particularly complex, as it involves a wide range of processing technologies and energy demands, from fresh cheeses to long ripened products. This study presents an evaluation based on Environmental Product Declarations and Life Cycle Assessment applied to different cheese typologies. Environmental impacts are assessed across the main production stages within system boundaries covering milk production and cheese manufacturing. Energy consumption is explicitly separated into electricity and thermal energy, allowing the identification of process specific environmental hotspots and improvement options along the production chain. Sensitivity analyses are performed to examine the influence of alternative energy sources, changes in electricity mix composition, and variations in process energy efficiency. This analysis supports the evaluation of result stability and highlights the role of energy related strategies in determining the environmental performance of different cheese categories. To increase the relevance of the results for decision making, environmental impacts are also related to nutritional value through a nutritional Life Cycle Assessment approach. Impacts are expressed in relation to the content of nutrients and selected micronutrients, such as proteins, energy, minerals and vitamins, enabling comparisons that extend beyond product mass and provide a more functionally meaningful assessment of sustainability. The results offer a practical benchmarking framework for the dairy industry and define a robust reference for future comparisons with protein alternatives derived from plant sources. This supports transparent sustainability communication, product design strategies, and evidence-based decision making.

Keywords – Cheese production; energy consumption; Environmental Product Declaration; Life Cycle Assessment; Nutritional Life Cycle Assessment

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DEVELOPMENT OF RESULT-BASED PAYMENT SCHEMES FOR CARBON FARMING

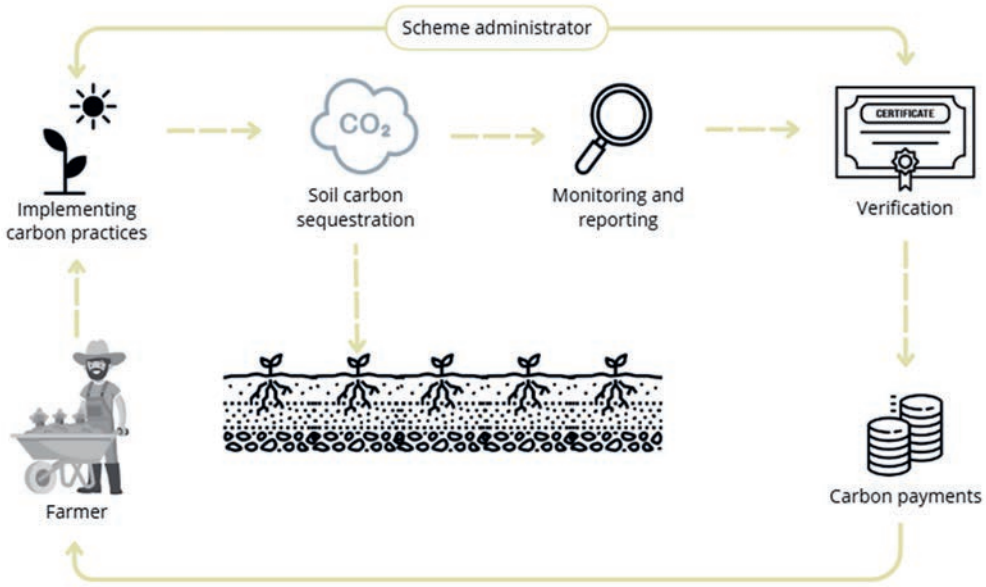
Alise AVOTIŅA[1*], Jeļena PUBULE[2], Ilze VAMŽA[3]

[1–3] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, Latvia*

[*] ***Corresponding author.*** *Email address: alise.avotina@edu.rtu.lv*

Abstract – The agricultural sector is a significant contributor to greenhouse gas emissions. However, through the implementation of carbon farming practices, it also possesses considerable potential not only for emission reduction but also for carbon sequestration. In recent years, carbon farming has been recognized as an important instrument for climate change mitigation while simultaneously improving soil quality and the efficiency of resource use. Nevertheless, while carbon farming practices have been widely discussed, carbon sequestration potential has not yet been consistently quantified in empirical terms. This study analyses carbon farming practices and their role in carbon sequestration, in order to identify the most suitable solutions for Latvia's specific climatic and soil conditions. The carbon sequestration potential of different agricultural practices in soils is assessed using an index-based approach. An emphasis is placed on the practices that are compatible with Latvia's climatic conditions and agronomic context, as the effectiveness of carbon farming measures strongly depends on local environmental factors. In order to motivate farmers to adopt carbon farming practices, economic incentives play a key role. For this reason, this study evaluates various agricultural support payment schemes, including direct payments, result-based payments, and hybrid payment schemes. Existing local solutions are analysed alongside the experience of European countries and Australia in implementing results-based payment schemes. The analysis highlights the advantages, disadvantages, and limitations of these schemes, with a focus on their applicability in the Latvian agricultural sector. The study also examines the potential functioning of an agricultural payment scheme in Latvia. In the practical part of the research, an interview was conducted with a farm, and the data obtained was used for a cost benefit analysis. The interview results indicate low motivation among farmers to participate in carbon farming payment schemes, both among farms that have not implemented such practices and those that have applied them over a longer period. At the same time, the interviewed farm acknowledges that the implementation of carbon farming practices has generated significant secondary benefits. Accordingly, the study also evaluates the secondary benefits of carbon farming practices, including improvements in soil quality and reductions in fuel consumption. The conclusions emphasize that results-based agricultural support payment schemes represent a promising instrument for the development of sustainable and climate neutral agriculture in Latvia. However, the findings indicate the need for improved communication with farmers regarding the benefits of carbon farming practices and the payment conditions to increase farmers' trust and willingness to participate. Furthermore, continued research is required to develop indexes for different climatic and soil conditions, increasing the predictability of potential financial benefits prior to participation in payment schemes.

Keywords – Agricultural economics; agricultural payment schemes; soil carbon sequestration; sustainable agriculture



Result-based carbon farming payment scheme

ACKNOWLEDGEMENT

The research was developed within the framework of the Fundamental and Applied Research Project "Carbon farming Certification system: The transition towards result based agriculture sector (CarbFarmS)", project No. lzp-2023/1-0055, funded by the Latvian Council of Science.

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CARBON FOOTPRINT ASSESSMENT IN ROAD CONSTRUCTION PROJECTS: METHODS FOR REDUCING EMISSIONS

Lakmal Madushanka Mudalige KAMMANGODA MUDALIGE*

Department of Environmental Protection and Water Engineering, Faculty of Environmental Engineering, Vilnius Gediminas Technical University, Saulėtekio Ave. 11, LT-10223 Vilnius, Lithuania

* ***Corresponding author.*** *Email address: lakmal-madushanka-mudalige.kammangoda-mudalige@stud.vilniustech.lt*

Abstract – Road construction represents a significant contributor to global greenhouse gas (GHG) emissions, yet standardised methodologies for quantifying and reducing these impacts remain underdeveloped in developing-country contexts, particularly in South Asia. This study aims to quantify the carbon footprint of road construction and identify technically and economically feasible emission reduction strategies through a comparative Life Cycle Assessment (LCA) of two infrastructure projects — the Outer Circular Highway (E02) in Sri Lanka and the A3 Motorway (Salerno–Reggio Calabria) in Italy — conducted using SimaPro software with the Ecoinvent v3 database, strictly following the four mandatory phases prescribed by ISO 14044. In the goal and scope definition phase, the functional unit is established as one kilometre of a standard two-lane road, and the system boundary is defined as cradle-to-gate, encompassing raw material extraction (A1), transport to manufacturer (A2), material production (A3), transport to construction site (A4), and on-site construction activities (A5). In the life cycle inventory (LCI) phase, material quantities, transport distances, and construction equipment fuel consumption data are compiled from project documentation, published LCA studies, and semi-structured stakeholder interviews; where Ecoinvent v3 datasets do not adequately represent Sri Lankan conditions, process-level adaptations are applied to reflect the local electricity grid composition, cement production characteristics, and regional supply chain distances. In the life cycle impact assessment (LCIA) phase, the IPCC 2021 GWP 100-year characterisation method is applied, expressing results in kg CO_2-equivalent per kilometre, complemented by the ReCiPe 2016 midpoint approach for additional impact categories. In the interpretation phase, Monte Carlo simulation and one-at-a-time sensitivity analysis quantify result uncertainty and identify the most influential parameters, while scenario analysis systematically evaluates emission reduction interventions including warm mix asphalt adoption, increased Reclaimed Asphalt Pavement (RAP) incorporation, local material sourcing optimisation, and construction equipment modernisation. Preliminary SimaPro modelling indicates significantly higher carbon intensity in the Sri Lankan case, attributable principally to near-absent RAP use (below 5 % versus 20–40 % in Italy), greater reliance on virgin construction materials, and a more carbon-intensive electricity grid. The study delivers a reproducible, ISO 14044-compliant methodological framework for carbon footprint assessment in tropical road construction, providing evidence-based guidance for Sri Lanka's Road Development Authority and analogous institutions across South Asia in meeting national climate commitments under the Paris Agreement.

Keywords – Ecoinvent database; greenhouse gas mitigation; ISO 14044; life cycle inventory; reclaimed asphalt pavement; SimaPro; Sri Lanka; warm mix asphalt

06

CIRCULAR ECONOMY SYSTEM. SUSTAINABILITY

https://doi.org/10.7250/CONECT.2026.072

LCA CASE STUDY OF NCM BATTERIES WITH END-OF-LIFE RECOVERY VIA PYROMETALLURGICAL PROCESSING

Amrutha RAJAMANI[1*], Giulia BAISINI[2], Nidhiben PATEL[3], Francesco ROMAGNOLI[4]

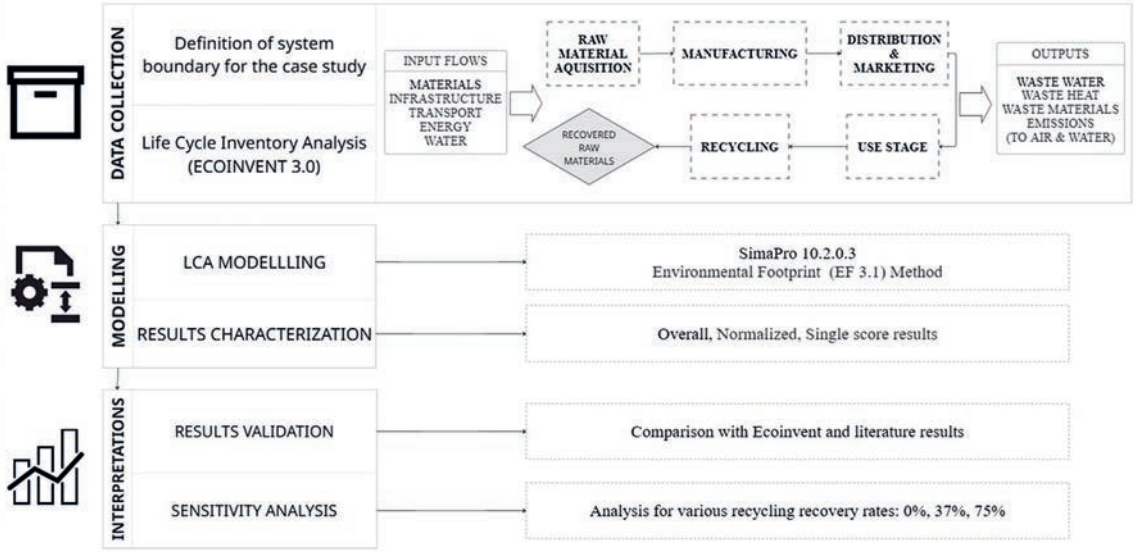
[1,3,4] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia*

[2] *Department of Mechanical and Industrial Engineering, University of Brescia, via Branze 38, 15-25121 Brescia, Italy*

[*] ***Corresponding author.*** *Email address: Amrutha.rajamani@edu.rtu.lv*

Abstract – This study performs a cradle-to-grave Life Cycle Assessment (LCA) of Nickel-Cobalt-Manganese (NCM) lithium-ion (Li-ion) batteries to evaluate their environmental performance across all life stages. The analysis is conducted using SimaPro 10.2.0.3 software with the Ecoinvent 3.10 database, following the Environmental Footprint (EF) 3.1 method and ISO 14040/14044 standards. The research system boundary includes resources and processes of the battery life stages from raw material acquisition, manufacturing, distribution and marketing, operational use, to the end-of-life (EoL) recycling through the pyro-metallurgical process. Analysis results reveal that battery production is the most significant contributor to environmental damage, particularly in categories such as climate change and resource use, due to high-energy manufacturing and the extraction of critical raw materials. While the use phase adds moderate greenhouse gas emissions, the distribution phase has a negligible impact. A primary focus on EoL recovery shows that pyrometallurgical recycling provides substantial environmental benefits, specifically in reducing fossil fuel, metal, and mineral resource depletion, by reclaiming valuable materials such as cobalt, nickel, and copper. These credits help offset production-related impacts by reducing the need for primary material extraction and refining. However, the recycling process introduces minor trade-offs, such as increased acidification burdens. The results are validated by comparing with other literature and the Ecoinvent analysis results. The deviations in results indicate the effects of geography, processes, and technology choices on the inventory. Sensitivity analysis further demonstrates that maximizing recovery rates is essential, as lower efficiency leads to a significant increase in the overall environmental footprint. These results highlight the necessity of advanced recycling technologies and improved production efficiency to support sustainable electric mobility. The novelty of the study lies in its comprehensive, cradle-to-grave approach, particularly its quantification of recycling, which demonstrates how recycling can provide significant economic benefits that help offset production-related impacts. The study also provides a transparent life cycle inventory (LCI) to help decision-makers evaluate the environmental performance of design and technology choices. This study addresses that gap by conducting a detailed LCA to demonstrate the impact of inputs at each stage, and the outcome can be strategically managed to achieve a sustainable battery life cycle. By analysing environmental damage and impact trade-offs across life stages, the study supports informed decision-making for sustainable battery management in electric mobility, emphasizing the need for improved production efficiency and advanced recycling technologies to minimize overall environmental footprint. The results show that, while production remains in the dominant hotspot, end-of-life recycling significantly improves the sustainability profile of LIBs, making closed-loop material recovery essential for future battery systems. This analysis and observations can also serve as a base case for future research on the lithium battery LCA, especially for comparing different EoL scenarios.

Keywords – Climate change; critical raw materials; electric mobility; Life Cycle Inventory; pyro-metallurgical recycling; sustainability



LCA framework of the NCM lithium-ion battery for the case study

ACKNOWLEDGEMENT

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MULTI-CRITERIA SUSTAINABILITY ASSESSMENT OF STRUCTURAL SYSTEMS FOR MULTI-STOREY BUILDINGS

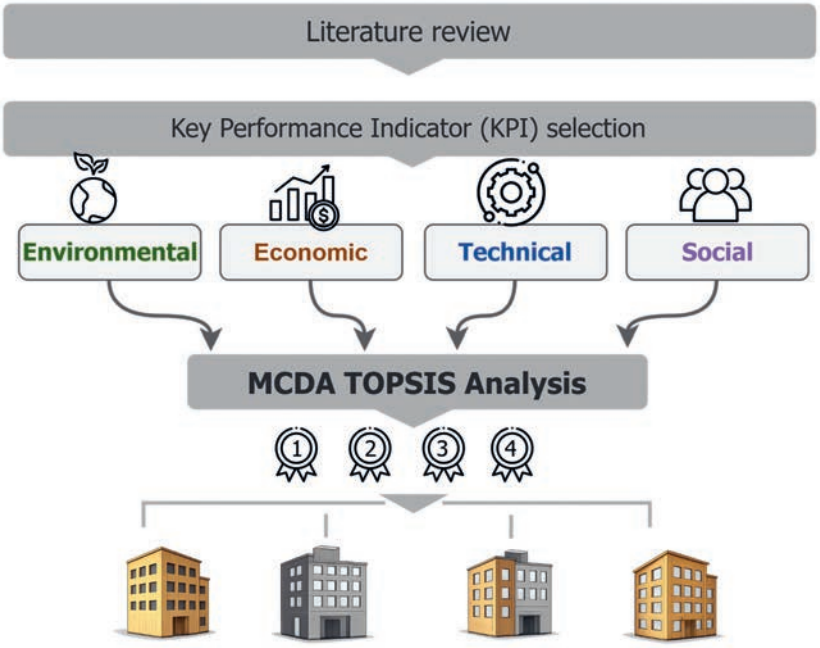
Valērija KOSTEVIČA[1*], Ilze VAMŽA[2], Megija VALTERE[3], Dagnija BLUMBERGA[4]

[1–4] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga LV-1048, Latvia*

[*] ***Corresponding author.*** *Email address: valerija.kostevica@rtu.lv*

Abstract – In Latvia, multi–story residential buildings are predominantly constructed using reinforced concrete (RC), while timber based structural systems remain underutilized. Despite the country's strong forestry sector, in the first part of 2025 multi-storey buildings constructed from timber accounted for only 8 % of newly completed buildings. This limited adoption can be explained by limited practical experience, regulatory barriers and concerns regarding cost, durability and long-term performance. This situation is notable given that Latvia ranks among worlds top ten exporters of key timber products, such as softwood sawn timber and birch plywood, highlighting a contrast between material production capacity and domestic application in multi-storey residential construction. At the same time, the building sector is responsible for a significant share of environmental impacts, prompting increased interest in alternative structural systems that can reduce carbon emissions while maintaining economic and social performance. Timber based structures such as cross-laminated timber (CLT) and glulam can substantially contribute to climate mitigation goals. However, the sustainability performance cannot be evaluated based only on environmental aspect, as economic efficiency, technical performance and social acceptance has a big impact on feasibility of residential buildings. To address this challenge this study applies a multi-criteria analysis (MCDA) approach to systematically compare timber, concrete and hybrid structural solutions. An MCDA approach based on the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) was developed to rank four structural alternatives: CLT, RC, hybrid CLT-RC, and glulam building. The evaluation was conducted using comprehensive set of key performance indicators grouped into four sustainability dimensions, where indicators were selected through a systematic literature review, while social dimension indicators were defined and refined based in stakeholder interviews. The proposed framework provides a structured basis for sustainable oriented decision making and supports the evaluation of timber, concrete and hybrid based structural systems for multi-storey building designs.

Keywords – Carbon sequestration; cross-laminated timber; MCDA; reinforced concrete; sustainability assessment



MCDA based framework for comparing structural systems in multi-storey buildings

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IMPLEMENTING SAFE AND SUSTAINABLE BY DESIGN: A LIFE CYCLE COSTING APPROACH FOR FIRE RETARDANT CHEMICALS IN WOOD PRODUCTS

Nidhiben PATEL[1]*, Chiara LEGGERINI[2], Francesco ROMAGNOLI[3]

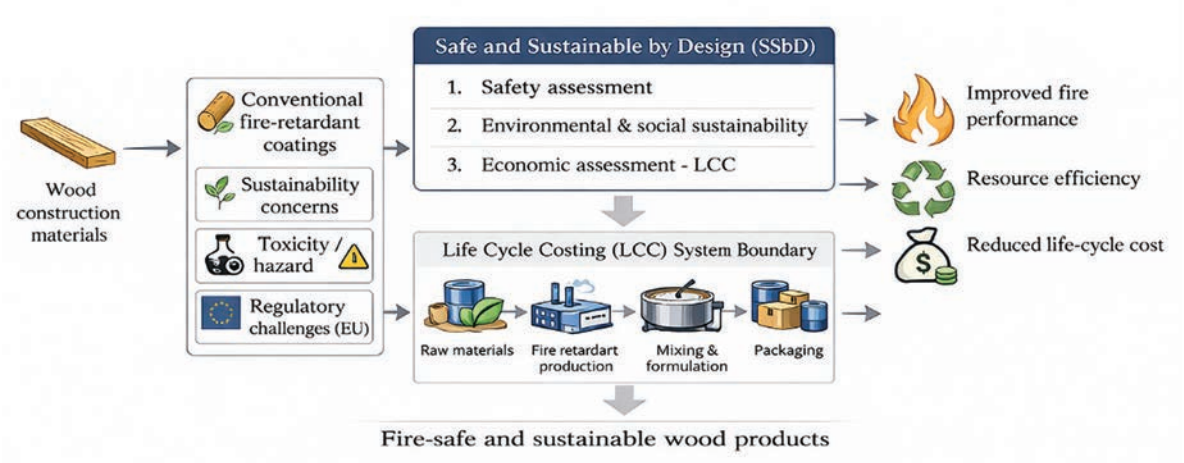
[1,3] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia*

[2] *University of Brescia, Department of Mechanical and Industrial Engineering, Via Branze 38 – 25123 Brescia, Italy*

* ***Corresponding author.*** *Email address: nidhiben-arvindbhai.patel@rtu.lv*

Abstract – The development of new fire-retardant chemicals for wood products is increasingly driven by the need to overcome the limitations of existing solutions, which often raise concerns regarding sustainability while failing to provide extended fire resistance performance. In this context, assessment approaches are required that support the integration of safety, sustainability, and economic considerations during early stages of chemical and product development. The Safe and Sustainable by Design (SSbD) framework provides overarching guidance for such integration by addressing environmental, social, functional, and economic dimensions across the life cycle. However, practical methodologies for implementing its economic dimension remain limited. This study focuses on operationalizing the economic pillar of the SSbD framework through the development of a Life Cycle Costing (LCC) methodology tailored to fire retardant chemicals for wood products. Within the SSbD concept, economic sustainability is interpreted beyond short-term production costs and includes long-term performance, resource efficiency, and the avoidance of future costs related to safety, regulatory compliance, and redesign. Based on this interpretation, LCC is selected as an appropriate tool to translate SSbD principles into a structured and transparent economic assessment. The LCC methodology is developed by defining system boundaries directly from an SSbD perspective, focusing on product system stages where design and production decisions have a direct influence on safety, sustainability, and economic performance. Five key stages are considered: raw material procurement, fire retardant production, mixing and product preparation, product packaging, and quality and safety control. These stages represent the core processes involved in the development of fire-retardant products and allow the economic implications of SSbD oriented choices to be systematically captured. For each stage the cost categories are identified and structured in alignment with SSbD principles. Particular emphasis is placed on linking economic assessment to functional performance, including improved and longer-lasting fire resistance, as well as to the substitution of less sustainable fire-retardant solutions. The proposed methodology demonstrates how the economic dimension of the SSbD framework can be transformed into a practical and application-oriented LCC approach. It supports transparent comparisons of alternative fire-retardant formulations and production strategies and provides a structured basis for SSbD-based decision-making in the development of fire-safe, economically viable, and more sustainable wood products.

Keywords – Decision-support framework; Economic assessment; Fire safety engineering; Material sustainability; Performance-based evaluation; Product system analysis.



SSbD based LCC fraemwork for developing new fire retardant

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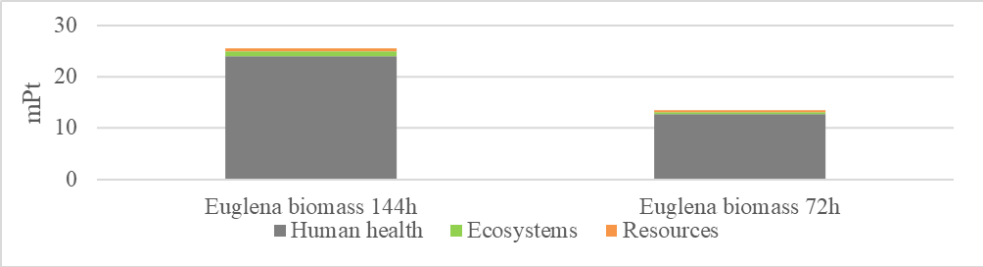
LIFE CYCLE ASSESSMENT (LCA) OF EUGLENA GRACILIS CULTIVATION ON FOOD INDUSTRY RESIDUES UNDER PURPLE LED STRIPS LIGHTS

Sara ALLAHVERDIYEVA[1*], Valeria MEZZANOTTE[2], Elena COLLINA[3], Marco MANTOVANI[4], Francesco ROMAGNOLI[5]

[1–4] *University of Milano-Bicocca, DISAT, Piazza della Scienza, 1, Milan, Italy*
[5] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia*
[*] ***Corresponding author.*** *Email address: s.allahverdiyeva1@campus.unimib.it*

Abstract – Microalgae provide a promising alternative for aquaculture, containing more than 40 % of protein, and up to 80 % of carbohydrates as β-1,3-glucan. The cultivation cost of Euglena biomass at a laboratory scale is estimated at €2.14 per kilogram, while at industrial scale it exceeds €5 per kilogram, highlighting the need to explore more cost and resource-efficient approaches. This study focuses on Life Cycle Assessment (LCA) of Euglena gracilis cultivation on liquid digestate and vinasse under purple LED strip lighting during a 144-hour growth period, which provides the highest biomass and paramylon production at laboratory scale. The research was performed using SimaPro software (version 10.1, 2022), and Ecoinvent database (version 3.10). Environmental impact assessment was carried out using the ReCiPe 2016 Midpoint (H) and Endpoint (H) methods. The system boundaries focus on the core stages of microalgae production, including sterilisation, cultivation, harvesting and drying, while upstream and downstream processes were excluded. The results show that nearly 93 % of the total environmental impact originates from the cultivation stage, which accounts for 0.8005 kg CO_2 eq. out of a total Global Warming Potential impact of 0.8551 kg CO_2 eq. Meanwhile impacts associated with the sterilisation, harvesting and drying stages were negligible for most categories, accounting for less than 6 %. Following this observation, the cultivation duration was assumed to be reduce by 50 %, while maintaining the approximate biomass amount and higher paramylon accumulation during this period. The results demonstrate that halving the cultivation duration from 144 to 72 hours reduced the total environmental damage from 25.55 to 13.51 mPt, corresponding to a 47.15 % decrease, indicating a highly dependence of total environmental performance on cultivation time. These findings suggest that optimising cultivation duration can improve the environmental performance of Euglena biomass production, while also reducing energy use and associated costs at a potential industrial scale. Although laboratory studies on the LCA of microalgae production remains limited, these results can provide essential insight to support the implementation of cultivation processes at industrial scale for aquaculture applications.

Keywords – Euglena gracilis; microalgae cultivation; Life Cycle Assessment (LCA); algal biomass production



Endpoint single score results (mPt) for 144 h and 72 h cultivation durations

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EVALUATING SUSTAINABLE MOBILITY SOLUTIONS: A CASE STUDY OF A UNIVERSITY CAMPUS

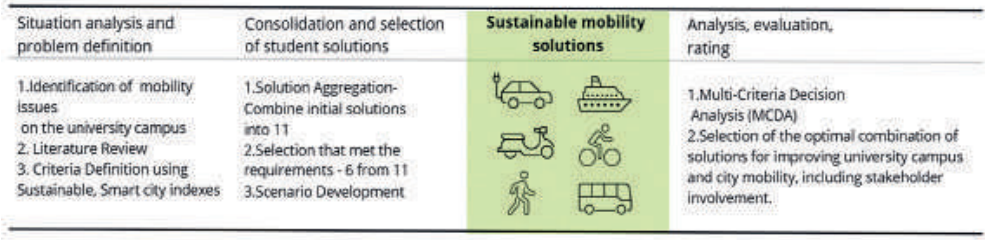
Undine GABRANOVA[1*], Andra BLUMBERGA[2], Zane PIPKALEJA[3]

[1–3] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, LV-1048 Riga, Latvia*

[*] ***Corresponding author.*** *Email address: undine.gabranova@rtu.lv*

Abstract – The transport sector is one of the largest sources of emissions in Latvia, accounting for the 31.4 % of country's total greenhouse gas emissions (GHG). In addition, compared to other European countries, residents own a high proportion of old vehicles, which exacerbates the situation. Taking into account international urban development and mobility assessments, including the TomTom Traffic Index, IMD Smart City Index, and IESE Cities in Motion Index, Riga, as the capital of Latvia, demonstrates a positive development trend, but this is not reflected in the reduction of GHG. Time constraints, comfort, limited access to public transport, high dependence on private cars, and inefficient connections to other cities are just some of the barriers that prevent residents from switching to more environmentally friendly modes of transport. Behavioural change can be achieved through various incentives. From an urban planning perspective, the contextual significance of an area and the availability of infrastructure can either encourage or discourage certain behaviours. The university campus was chosen as the location for the case study due to its spatial characteristics. It is located on an island, which, due to limited traffic flow, creates access problems for both students and teaching staff, encouraging the use of private vehicles. Considering that a university is a place where new ideas are born and where a large number of innovators and early adopters may gather environmental engineering students were tasked with solving the above-mentioned problems by creating ideas that meet climate-neutrality requirements as part of their course. Of the initial 26 solutions, 11 were combined. Of these, 6 were selected that met the requirements. The solutions include: (1) Park&Flow suburban parking lot integration with the public water transport system; (2) Micro-mobility point accessibility and development; (3) Prioritizing pedestrians on the university campus and on the way to it; (4) Unmanned electric minibuses; (5) Restricting motor vehicle access, electrifying the vehicle fleet, and optimizing and greening parking spaces; (6) A system for motivating cyclists based on behavioural incentives. These were analysed using Multi-Criteria Decision Analysis, taking into account the criteria set out in the above literature review.

Keywords – Emission reduction; Framework for Assessing and Selecting Sustainable Mobility Solutions; mobility behaviour; Multi-Criteria Decision Analysis (MCDA); transportation planning; travel patterns; university campus incentives



Framework for Assessing and Selecting Sustainable Mobility Solutions

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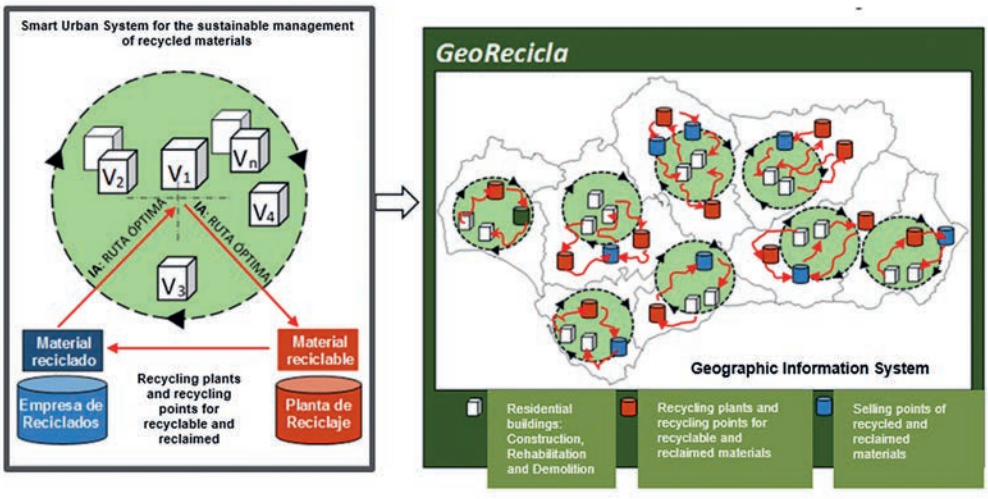
GEORECICLA: A TOOL TO BRIDGE DESIGN AND WASTE MANAGEMENT TO ENABLE CIRCULAR CONSTRUCTION IN ANDALUSIA, SPAIN

Bernardette SOUST-VERDAGUER[1*], Daniel CAGIGAS[2], Luis Angel CASTRO[3], José Antonio GUTIERREZ MORENO[4], María Dolores FERNÁNDEZ GALVÉZ[5], Alicia Isolina VÁZQUEZ[6], María Victoria MONTES[7], Rocío QUIÑONES[8], Isidro CORTÉS[9], Carmen LLATAS[10]

[1] *Departamento de Construcciones Arquitectónicas I, Universidad de Sevilla, Spain.*
[2,3,6,10] *Departamento de Arquitectura y Tecnología de Computadores, Universidad de Sevilla, Spain.*
[4,5,7–9] *Departamento de Construcciones Arquitectónicas II, Universidad de Sevilla, Spain.*
[*] ***Corresponding author.*** *Email address: bsoust@us.es*

Abstact – Current circularity and decarbonisation challenges in the construction sector increasingly promote reuse, reclamation, and recycling as key strategies to reduce environmental impacts and dependence on virgin raw materials. However, in Spain – particularly in Andalusia – significant barriers continue to hinder their effective implementation. A major challenge is the limited integration between the project design phase and local suppliers of recycled and sustainable construction materials, which restricts informed material selection from the early stages of design. This issue is further compounded by the lack of effective tools to optimise construction and demolition waste (CDW) management and to encourage the use of recycled and reclaimed materials. This research addresses these gaps through the development of GeoRecicla, an innovative digital decision-support platform that integrates Artificial Intelligence (AI) and Geographic Information Systems (GIS). The platform combines spatial data on housing locations with databases of recycled and reusable material suppliers and CDW recycling facilities across Andalusia. AI-based algorithms are employed to optimise transport routes and material flows throughout the building life cycle, supporting both material selection and waste management decisions.

Keywords – Artificial Intelligence (AI), circularity; construction materials; construction waste; GIS; recycled and reclaimed construction materials; residential buildings



GeoRecicla framework for reuse, reclaim and recycling material management in Andalucía

ACKNOWLEDGEMENT

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SUSTAINABILITY INDEX DEVELOPMENT FOR BIOSURFACTANTS IN CLEANING PRODUCTS USING BIBLIOMETRIC ANALYSIS

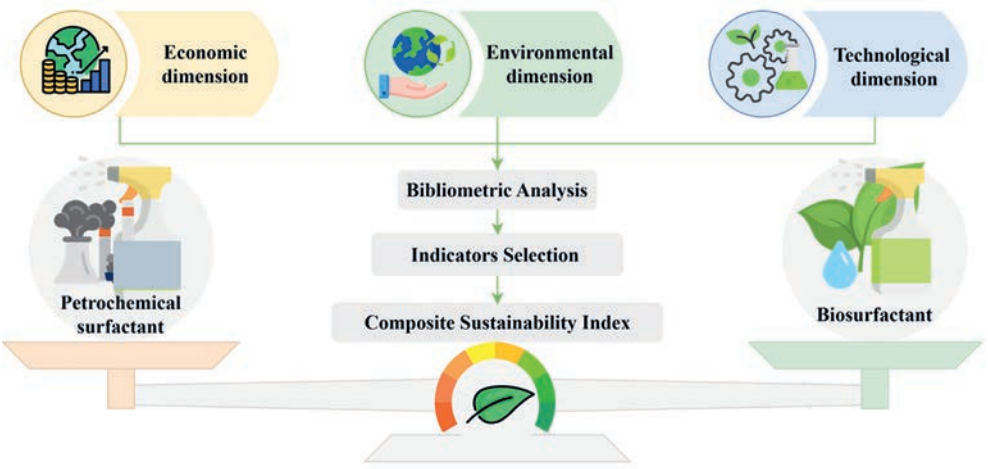
Jelizaveta PALCEVSKA[1*], Annija LOCE[2], Ilze VAMZA[3], Dagnija BLUMBERGA[4]

[1–4] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia*

[*] ***Corresponding author.*** *Email address: jelizaveta.palcevska@rtu.lv*

Abstract – Growing interest in environmentally friendly cleaning products has led to increased attention to biodegradable surfactants, particularly biosurfactants, as an alternative to traditional petrochemical surfactants. A large part of petrochemical surfactants is harmful to the environment, as they degrade poorly and pollute water environments. Therefore, biosurfactants offer a sustainable alternative; they are of natural origin, less toxic and easily degradable. The aim of the study is to analyse biosurfactant technology, its economic and environmental aspects, and to apply it to cleaning products by developing a structured sustainability index. The bibliometric analysis method was used to determine the indicators for the three main sustainability dimensions, which were defined as technological, environmental and economic. From the Scopus database, all-keywords co-occurrence was generated and visualized by using the VOSviewer software. The analysis was used to identify frequently occurring keywords related to the three dimensions in the biosurfactant literature. The related keywords were grouped according to their relevance to the environmental, economic, and technological sustainability dimensions, and then defined as indicators. These indicators show the key aspects discussed in the literature, like biodegradability, pollution, production, optimization and cost-related factors. The study results highlight an imbalance in the current scientific agenda: while significant attention is paid to the production and environmental performance of biodegradable surfactants, the market and economic aspects of their implementation remain relatively underrepresented. The proposed integrated methodological framework is a transparent, data-driven assessment tool that will provide a foundation for future research on biosurfactants and sustainable cleaning products, across technology, economy and environment.

Keywords – Bibliometric analysis; biodegradable surfactants; biosurfactants; cleaning products; composite sustainability index; sustainability; economic aspects



Methodological framework for biosurfactant sustainability evaluation

ACKNOWLEDGEMENT

This work has been supported by the EU Recovery and Resilience Facility within Project No 5.2.1.1.i.0/2/24/I/CFLA/003 "Implementation of consolidation and management changes at Riga Technical University, Liepaja University, Rezekne Academy of Technology, Latvian Maritime Academy and Liepaja Maritime College for the progress towards excellence in higher education, science and innovation" academic career doctoral grant (ID 1087).

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BEYOND ENVIRONMENTAL LCA: INTEGRATING WORKER SOCIAL RISK INTO THE SUSTAINABILITY ASSESSMENT OF CONSTRUCTION MATERIALS

Davide DE VITO[1], Irene MAZZEI[2], Elisabetta PALUMBO[3*]

[1,3] *Department of Engineering and Applied Science (DISA), University of Bergamo, Viale G. Marconi, 5, 24044 Dalmine (Bergamo), Italy*

[2] *York School of Architecture, Piazza Building, Deramore Lane, Heslington, York, YO10 5GJ, United Kingdom*

[*] ***Corresponding author.*** *Email address: elisabetta.palumbo@unibg.it*

Abstract – The selection of construction materials is becoming increasingly central in building-scale sustainability assessments. However, such evaluations still predominantly focus on environmental aspects. Some certification schemes, such as the EU Ecolabel for the "Hard Coverings" product group, address social aspects related to worker safety and labour conditions by requiring evidence of policies, procedures and operational measures that ensure worker protection throughout the quarrying process. These aspects, however, are not extended to other product families within the same category, despite involving activities that entail comparable occupational risks. Previous studies conducted in the Italian context on worker safety within the steel and concrete supply chain have shown that relying solely on environmental metrics may obscure critical social risks embedded in material production, particularly those related to labour conditions and accident rates. These studies demonstrate that integrating social and environmental life cycle perspectives enables a more comprehensive understanding of sustainability performance, supporting material choices that address not only carbon reduction but also the well-being and protection of workers throughout the supply chain. A practical way to integrate social considerations into Environmental Life Cycle Assessment (E-LCA) is to adopt a combined assessment framework that complements traditional impact categories with social risk indicators derived from sector-specific data. Building on this approach, integration can be achieved by coupling standard E-LCA with elements of Social Life Cycle Assessment (S-LCA), using worker-related metrics – such as accident frequency and severity rates and documented safety conditions – as quantitative indicators of social performance. By analysing accident databases, national labour statistics and information on working practices, these indicators can be normalised and incorporated into the interpretation phase of the LCA, allowing social risks to be assessed alongside environmental burdens. This enables a systematic comparison of construction materials not only in terms of emissions or resource use, but also with respect to the human cost embedded in their supply chains. Starting from the requirements introduced by Criterion 2.5 of the EU Ecolabel for natural stone (personnel safety and working conditions at the quarry), this contribution proposes a methodological approach to integrate social assessment alongside E-LCA for construction materials subject to similar risks. The aim is to outline a way to complement existing environmental impact labels, such as Environmental Product Declarations (EPDs) – third-party labels based on E-LCA studies – by making them more comprehensive. To illustrate the applicability of the proposed method, the study integrates E-LCA analyses conducted on hard covering products with risk indicators

related to worker safety. Future developments include extending the proposed approach to its direct application within production processes, enabling companies to integrate social indicators into internal sustainability assessment practices and to monitor worker-related risks alongside environmental performance.

Keywords – EU Ecolabel; Life cycle sustainability assessment; working conditions; workers health and safety; worker and labour conditions

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ASSESSING CIRCULARITY POTENTIAL IN THE EAST-AFRICAN TEXTILE INDUSTRY: A CASE STUDY OF KENYA'S LARGEST TEXTILE FACTORY

Mariliis HALJASORG[1*], Harri MOORA[2], Reet AUS[3], Ingrid VAROV[4], Josphat IGADWA MWASIAGI[5]

[1,3] *Estonian Academy of Arts, Põhja pst 7, 10412 Tallinn, Estonia*
[2,4] *Stockholm Environment Institute Tallinn Centre, Erika 14, 10416 Tallinn, Estonia*
[5] *Moi University, 3900-30100 Eldoret, Kenya*
[*] ***Corresponding author.*** *Email address: mariliis.haljasorg@artun.ee*

Abstract – Over recent decades, the African textile industry has experienced a marked decline due to structural challenges, including outdated production technologies, low energy and resource efficiency, and limited industrial policy support. A particularly significant factor has been the large-scale import of low-cost second-hand textile products from Europe and other highly developed countries, displacing locally manufactured textiles and undermining the competitiveness and economic viability of local producers. In response, improving resource efficiency through circular economy approaches has emerged as a potential pathway to revitalise the sector. However, limited recycling infrastructure, insufficient data on industrial textile waste, and gaps in design and organisational capacity constrain the adoption of circular practices. This study assesses the potential for circularity in the Eastern African textile industry through a case study of Rivatex, one of the largest vertically integrated textile and garment manufacturers in Kenya. The research applies a mixed-methods case study approach, including systematic mapping of textile waste and fabric leftovers across all production divisions to quantify waste streams and identify opportunities for industrial-scale upcycling. In addition, factory-level waste upcycling was integrated with product-level life cycle assessment (LCA) to evaluate the environmental performance of circular textile products. The results show that the factory generates approximately 600 tonnes of textile waste annually. Around 20 % of this material could be used directly in the factory to produce new textile products without requiring technological upgrades or capital investment. The main barriers identified were a lack of design knowledge, skills, and organisational arrangements for factory-based upcycling. To demonstrate the feasibility of this approach, two upcycled jackets were designed and produced from production waste and compared with a conventionally manufactured jacket made from virgin cotton fabric. The comparative LCA indicates substantial environmental benefits for the upcycled products, with reductions in climate change impacts of 93 % and 78 % and reductions in fossil energy use of 93 % and 70 %, respectively. Even greater savings were observed for water and land use. Overall, the findings demonstrate the high potential of integrating industrial textile waste mapping with design-led upcycling and life cycle assessment to support circular production models in Africa. Such approaches can significantly enhance resource efficiency, reduce environmental impacts, and create new economic opportunities, providing a viable pathway to improve the competitiveness and long-term sustainability of the East African textile industry.

Keywords – Circular textiles; industrial upcycling; life cycle assessment; textile waste

ACKNOWLEDGEMENT

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DEVELOPMENT OF A SOCIAL LIFE CYCLE ASSESSMENT INDICATOR FRAMEWORK FOR CO_2 MARINE TRANSPORT IN CCS VALUE CHAIN

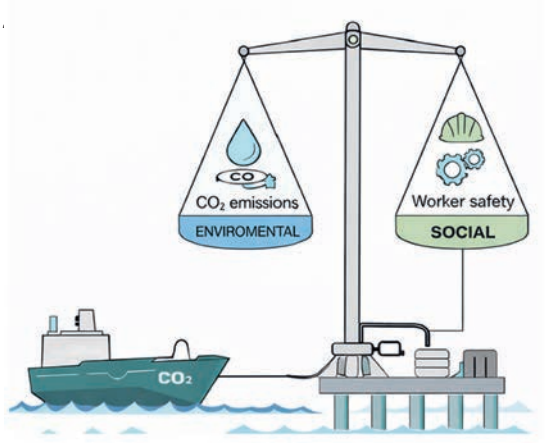
Ance ERDMANE[1*], Dace LAUKA[2], Jūlija GUŠČA[3]

[1–3] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, LV-1048 Riga, Latvia*

[*] *Corresponding author. Email address: Ance.Erdmane@edu.rtu.lv*

Abstract – Carbon Capture and Storage (CCS) is increasingly recognised as an essential component of climate mitigation strategies, particularly for industrial sectors with limited decarbonisation alternatives. As CCS systems evolve towards larger scale and transboundary deployment, the sustainability of CO_2 transport infrastructure becomes a critical consideration. While marine transportation of CO_2 is gaining attention as a flexible and scalable transport option, existing studies have largely focused on technical performance and economic aspects, with comparatively limited attention to structured social sustainability assessment. This study presents the development of an indicator-based Social Life Cycle Assessment (S-LCA) framework that focuses on the structuring and operationalisation of social sustainability indicators for CO_2 marine transportation within emerging CCS value chains, rather than on impact interpretation or performance evaluation. The framework is operationalised through a multi tab Excel-based inventory that enables systematic organisation of sustainability information across several analytical layers. The framework organises social sustainability assessment through defined categories, impact subcategories and indicators assigned to each CO_2 marine transport value chain participant. The proposed indicator set addresses key social sustainability themes relevant to CO_2 marine transport, such as occupational health and safety, working conditions, employment quality, local community safety perception, access to information, emergency preparedness, and transparency and governance practices.

Keywords – Decarbonized transport systems; maritime CO_2 logistics; stakeholder indicators; social sustainability assessment



Conceptual illustration of the relationship between environmental performance and social aspects in offshore CO_2 transport and storage activities

ACKNOWLEDGEMENT:

This research is funded by the project "Efficient and Sustainable Maritime Infrastructure for CCS Logistics in the Nordic and Baltic Countries (LogiCCS)" under the Clean Energy Transition Partnership within the 2024 joint call for research proposals. The project is co-funded by the European Commission (Grant Agreement No. 101069750) and the national funding organizations listed at: https://cetpartnership.eu/funding-agencies-and-call-modules.

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STREAMS TOWARDS GLASS SUSTAINABILITY

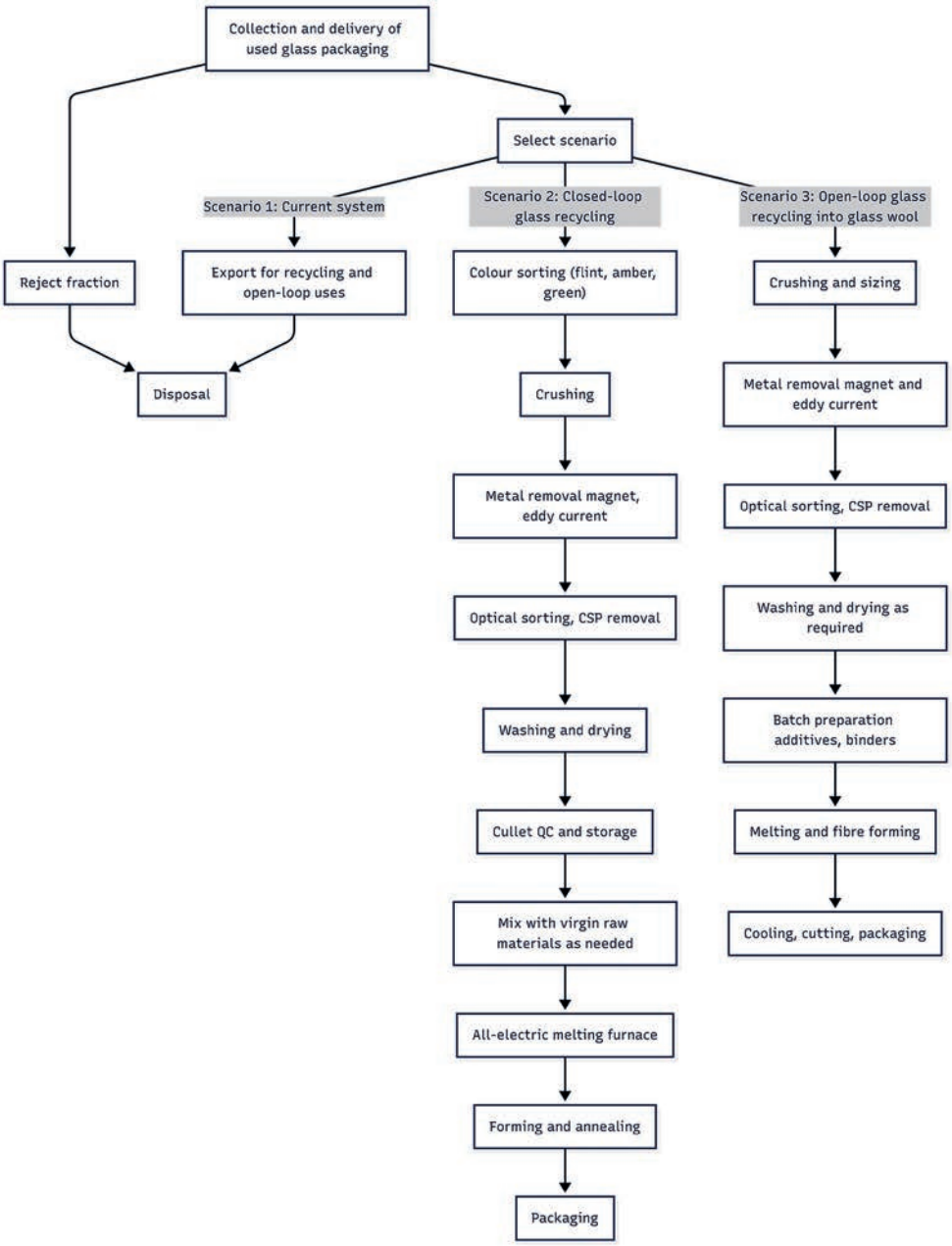
Daniela PUTERE[1*], Terēza BEZRUČKO[2], Veronika LIBEROVA[3], Dagnija BLUMBERGA[4]

[1–4] *Institute of Energy Systems and Environment, Azenes iela 12/1, Riga, LV-1048, Latvia*

[*] ***Corresponding author.*** *Email address: daniela.putere@edu.rtu.lv*

Abstract – The authors identify the largest recyclable streams still landfilled in Latvia or exported from Latvia and focus on packaging glass due to its high circularity potential and the lack of domestic closed-loop glass recycling into new container glass. Official waste statistics (2023–2024) were analysed to quantify landfilled and exported flows by waste class and to identify priority streams (> 5000 tons per year). A scenario-based material flow algorithm was developed for glass waste and linked to a plant concept design. Three scenarios were compared: 1) current system (mainly glass export and local downcycling), 2) domestic closed-loop glass recycling (sorting, washing, and cullet remelting into new container glass), and 3) open-loop glass recycling - glass wool manufacturing. A techno-economic (TEP) and life cycle assessment (LCA) framework was applied across scenarios. Municipal waste landfilled totalled 418301 tons in 2023 and 363336 tons in 2024, dominated by mechanical-treatment residues and biodegradable fractions, for which national waste management plans already include recycling measures. Packaging glass shows a clear capacity gap – export for recycling reached 29438 tons in 2023 and 36272 tons in 2024, while domestic recycling remains limited to lower value applications. The scenario analysis shows that domestic closed-loop glass recycling is technically feasible given the observed glass flows. Its environmental performance is expected to depend primarily on the electricity supply, achievable cullet share, cullet quality, transport distances, and furnace energy source. Domestic closed-loop glass recycling would reduce reliance on export and support higher material circularity. The scenario algorithm and conceptual plant design provide a framework for completing the final TEP/LCA and for screening investment options.

Keywords – Circular economy; closed-loop recycling; Life Cycle Analysis (LCA); packaging glass; Techno-Economic Performance (TEP) assessment



Scenario based material flow algorithm

ACKNOWLEDGMENT

This research was supported by the EU Recovery and Resilience Facility within Project No 5.2.1.1.i.0/2/24/I/CFLA/003 "Implementation of consolidation and management changes at Riga Technical University, Liepaja University, Rezekne, Academy of Technology, Latvian Maritime Academy and Liepaja Maritime College for the progress towards excellence in higher education, science and innovation" academic career doctoral grant (ID 1033).

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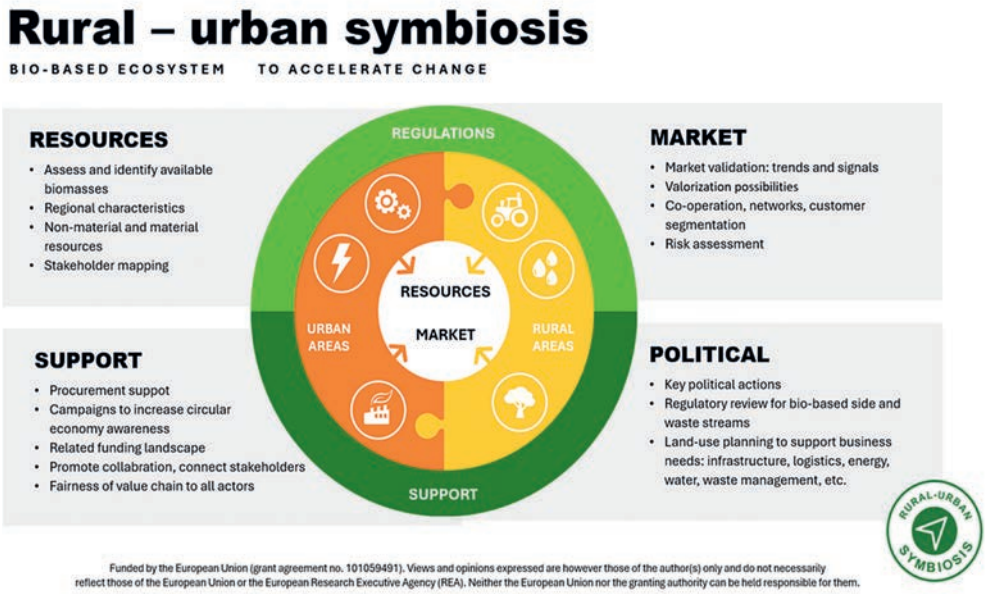
CREATING CIRCULAR ECONOMY MARKETS, BUSINESS MODELS AND BIOBASED VALUE CHAINS WHILE BOOSTING THE URBAN-RURAL SYMBIOSIS

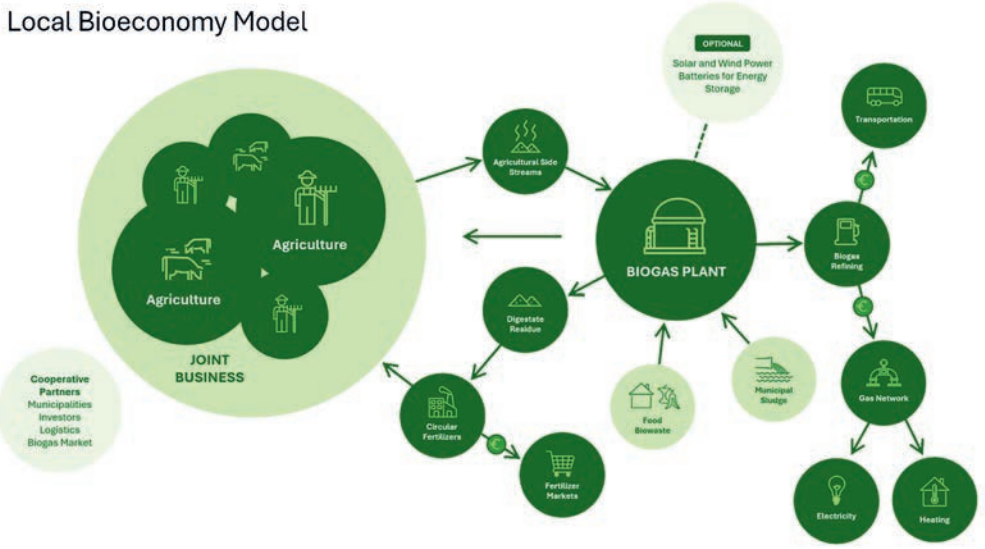
Riina KÄRKI*[1], Jaana KOIVISTO[2], Magdalena EDVARDSEN[3]

[1] *Central Union of Agricultural Producers and Forest Owners (MTK), Helsinki, Finland*
[1] *University of Helsinki, Fabianinkatu 33, 00100 Helsinki, Finland*
[2] *Ekokumppanit Oy, Puutarhakatu 11 A, 33210, Tampere, Finland*
[3] *Fredrikstad Municipality, Fredrikstad, Norway*
* ***Corresponding author.*** *Email address: riina.karki@mtk.fi*

Abstract – A sustainable circular bioeconomy must rely on the efficient use of raw materials while promoting the utilization of local resources. In close collaboration with farmers, industries, municipalities, and regional stakeholders, TREASoURcE project developed circular bioeconomy markets and business models, fostering the establishment of biobased value chains, and investigates opportunities to utilize urban and rural waste and side streams. During the project time frame, we have developed several circular bioeconomy solutions. **First**, the project has created and launched a digital marketplace for biobased by-products and waste streams, KiertoaSuomesta.fi. The platform connects material suppliers with potential buyers, as well as providers of related services, machinery and other relevant resources. Its primary target groups include companies generating biobased side streams from agriculture, forestry, and food processing, as well as raw material–using industries and public sector organizations. **Second**, the project examined opportunities to develop local bioeconomy ecosystems, with biogas plants at their core. Municipalities play a key role in advancing these ecosystems as they are striving for carbon-neutral energy production, and local biogas generation offers a practical solution. The project conducted surveys to assess local bioeconomy models in small municipalities in the Tampere region (Pirkanmaa), Finland. Based on these findings, a framework outlining the fundamental principles for developing and implementing a local bioeconomy model was created. *The local bioeconomy model* was presented as an example of the objectives promoted by the Rural–urban symbiosis Tool and as a practical illustration of how such a model can be implemented. **Third**, the Rural–urban symbiosis model encompasses both practices presented above and creates a conceptual framework for practical examples. The rural-urban symbiosis refers to the mutually beneficial relationship between cities and their surrounding rural areas. It highlights the exchange of resources, services, knowledge, and innovation in ways that create shared value and strengthen resilient, circular, and regionally integrated economies. *The Rural–urban symbiosis mode*l was developed to operationalize this concept. Hosted on the widely used Moodle learning management system, the tool is accessible, adaptable, and user-friendly for diverse audiences. The platform enables stakeholders to better understand and implement circular economy strategies tailored to their regional contexts. It serves as a strategic resource for municipalities, planners, businesses, and policymakers, helping them identify and harness biobased side and waste streams through innovative collaboration.

Keywords – Biobased value chains; biogas ecosystems; circular bioeconomy; digital marketplace; local bioeconomy models; rural–urban symbiosis; waste and side streams





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IMPACT OF TECHNICAL AND BEHAVIORAL MEASURES ON ENERGY SAVINGS IN SCHOOL BUILDINGS

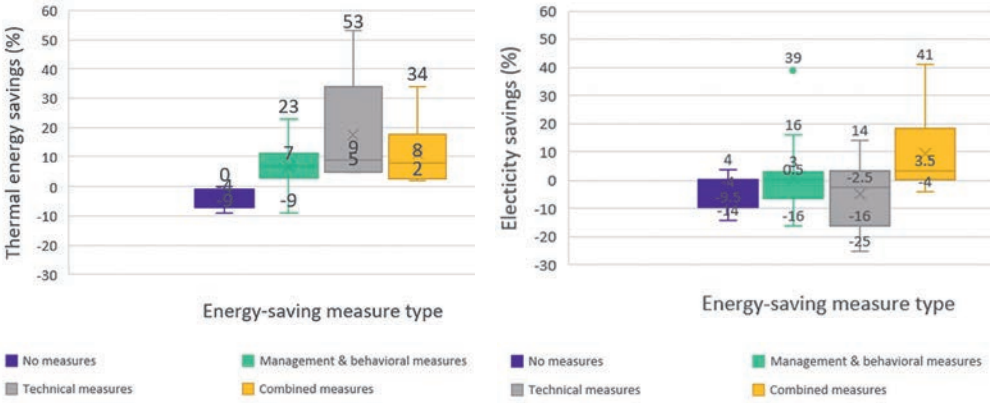
Inguna BREMANE[1*], Andra BLUMBERGA[2], Dagnija BLUMBERGA[3]

[1–3] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia*

[*] ***Corresponding author.*** *Email address: inguna.bremane@rtu.lv*

Abstract – Improving energy efficiency is a strategic priority within the framework of the European Green Deal and the Energy Efficiency Directive. In the public building stock, educational institutions account for a significant share of energy consumption. Improving the energy efficiency of school buildings simultaneously contributes to achieving climate goals, reduces operating costs for municipalities, and promotes the development of sustainable thinking in society by involving students as future decision-makers. Therefore, assessing the actual impact of different energy saving approaches is essential for evidence-based investment planning and effective implementation of climate policy. The study analyzed the energy savings of school buildings in three Latvian municipalities using a structured dataset on building characteristics, energy consumption and implemented energy saving measures during renovation, construction, and operation. The analysis revealed significant differences in the energy efficiency of buildings – the specific heat energy consumption of schools ranged from 42 to 181 kWh/m^2, indicating a significant untapped energy saving potential. The results show that thermal energy savings are mainly provided by capital-intensive technical measures, but management and user behavior measures can also have a significant effect, reaching savings of up to 23 %. The most stable results in terms of electricity consumption were achieved in buildings where technical solutions were combined with behavioral change and energy management approaches, with combined strategies providing the most balanced performance. The study highlights that targeted data analysis allows municipalities to identify priority buildings, select the most cost-effective measures, and accelerate emission reductions in the public sector. For municipalities with limited budgets, low-cost management and action measures can serve as an immediate first step, while preparing the ground for long-term renovation investments and facilitating the move towards climate neutrality.

Keywords – Educational buildings; energy efficiency; energy consumption; energy management



Methodological framework for biosurfactant sustainability evaluation

07

ENVIRONMENTAL AND ENERGY POLICIES AND FRAMEWORKS

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IS COP 31 2026 GOING TO BE A SWEET SPOT FOR RENEWABLES TRANSITION?

Prachi UGLE*

Safe Landing Climate, Sustainable Procurement Pledge Ambassador, UNFCCC, UNSDGs Global Platform, IUCN

* ***Corresponding author.*** *Email address: prachiugle@gmail.com*

Abstract – As we have leaped into 2026, it becomes imperative for the climate change mitigation machinery to tighten the purpose and practice for this year COP 31 2026 scheduled to be held later this year. What has the Conference of Parties (COP) given us all these years, false promises and futile negotiations with agreement not turning into enforcement for deployment and implementation. Putting the very purpose of COP into a questionable virtue of conduct. COP 30 2025 left behind non-consensus on climate multilateralism, fossil fuels phase out and uneven positioning of climate change adaptation and resilience. This has raised a big question as resilience as a best practice or a failing practice and putting straightforward practice and call as an immediate priority. Through this paper, a question to raise the deployment machinery is being put forth as "Is COP 31 2026 going to be a "SWEET SPOT" for renewables transition or whether the uneven shift will remain a "GREY SPOT" as Corporates are not going to shed their virtue of lobbying for fossil fuels in business. Why are corporate businesses allowed an entry to the Conference of Parties when it is a scientific consideration of processes and procedures for negotiations which later businesses need to implement on the basis of the enforcement and deployment machinery being agreed for. The corporates not just demean the purpose of the summit but downgrade the shift in transition towards renewables, as for them it is business as usual but for climate change action it only seeks beyond business "New Normal" with strengthened penetrative and transformative scientific solutions. Civil Societies over the years have been pushing hard for climate multilateralism and corporations still relish the subsidies on fossil fuels at the cost of the planet and people. The developed countries have majorly submitted their Nationally Determined Contributions (NDCs) however developing countries are falling short in practice and purpose for preparing the NDCs road map as it is failing in its strategy and target setting as well as procedural modalities. Of the 200+ countries which have ratified the Paris Agreement to reduce the global warming and temperature to well below 1.5 degrees centigrade, hardly few among them have been able to seize the tipping point for emission reductions as well as reducing the locally enabling heat Islands. Local Led Adaptation and Mitigation is key to comply with the Paris Agreement otherwise the temperature effect shall downgrade the planet and people together. The paper highlights and raises critical issues of concern on Non-confirmity to climate targets set as per NDCs as not all countries have uniformly submitted their NDCs which weakens the strength and penetration of climate change strategy across countries, cities and communities. The NDCs should include contributions under three criteria for : Country level, City level and Communities level and put Monitoring Reporting and Verification (MRVs) aligned and integrated with Monitoring, Reporting, Evaluation and Learning (MREL) framework as outcomes from every mitigation effort is learning from improving the best practices and benchmarking our own climate commitments and create self sufficient infrastructure for commitments to transitioned into transformative actions.

Keywords – Adaptation; climate change mitigation; COP 31; MREL; MRVs; multilaterism; NDCs

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A SCENE-BASED ANALYSIS OF THE VIDZEME TRANSITION ARENA FOR SUSTAINABILITY TRANSITIONS

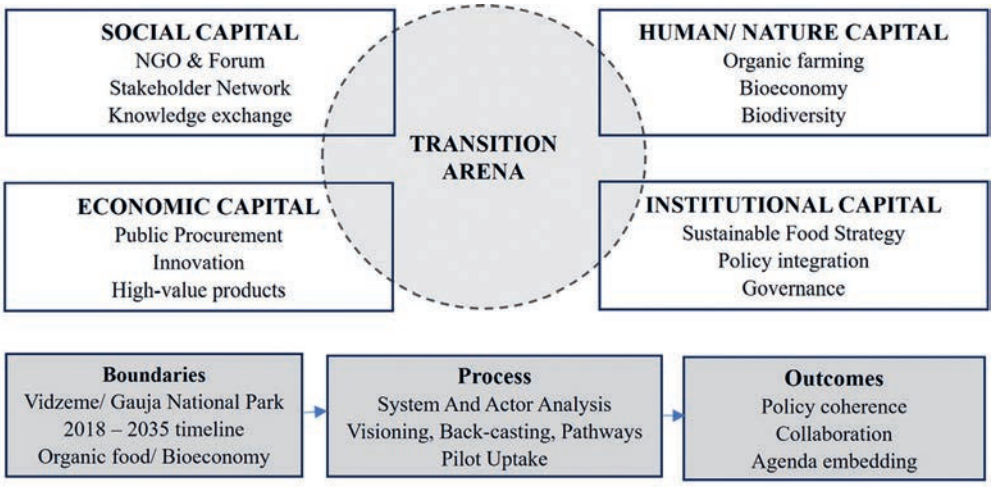
Zane PIPKALEJA[1*], Jelena PUBULE[2], Dace LAUKA[3]

[1–3] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Rīga, LV-1048, Latvia*

[*] ***Corresponding author.*** *Email address: zane.pipkaleja@rtu.lv*

Abstract – The world requires systematic methods that will help organizations achieve sustainable development during their transition from current to future states. The current situation has led to increased adoption of new governance systems that unite social elements, natural resources, economic factors, and institutional structures through formal participation methods. The Transition Arena approach addresses this requirement through its method, which unites system and actor analysis with visioning, back-casting, pathway development, and pilot experimentation within specific geographical and time-based limits. The combination of these elements creates systemic transformations that improve policy consistency and enable different sectors to work together. The research investigates the Vidzeme Transition Arena through the SCENE framework to evaluate its role as a strategic tool for sustainability transitions, while analysing social, human-nature, and economic and institutional changes within a bioregion setting. The case builds on the application of the Transition Arena methodology to the organic food transition to support the development of the Gauja National Park bioregion in Vidzeme. The program began operations in 2023 through system and actor analysis, then progressed to co-creation and visioning workshops in 2024, and then conducted pilot actions from 2024 through 2025. The process required three essential elements: developing a common long-term plan with ten-year goals, using back-casting techniques, and specifying implementation strategies. The SCENE-based analysis reveals essential system stocks, including stakeholder networks, organic farming capacities, and governance structures, and it also shows active knowledge transfer and organic food implementation in public dining programs and in policy coordination. The pilot initiative demonstrates how small-scale experiments can become lasting components of the Bioregion Action Plan and the Vidzeme Sustainable Food Strategy 2035. The Transition Arena serves as a core system that links niche activities to sustainable development projects that deliver benefits for all residents in the area.

Keywords – Bioeconomy; co-creation methods; eco-social transitions; innovation; sustainable governance; transition arena



Research framework for Transition Arena in Vidzeme

ACKNOWLEDGEMENT

The work was developed within the framework of the EU ERDF-funded project "RTU Doctoral Grants for Supporting Scientific Excellence in Smart Specialization Areas" (No. 1.1.1.8/1/24/I/007) within the framework of a doctoral grant (ID 8005).

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CHARACTERISTICS OF LATVIAN NON-INDUSTRIAL FOREST OWNERS AND THEIR POSSIBLE ROLE IN THE SPREAD OF THE SPRUCE BARK BEETLE

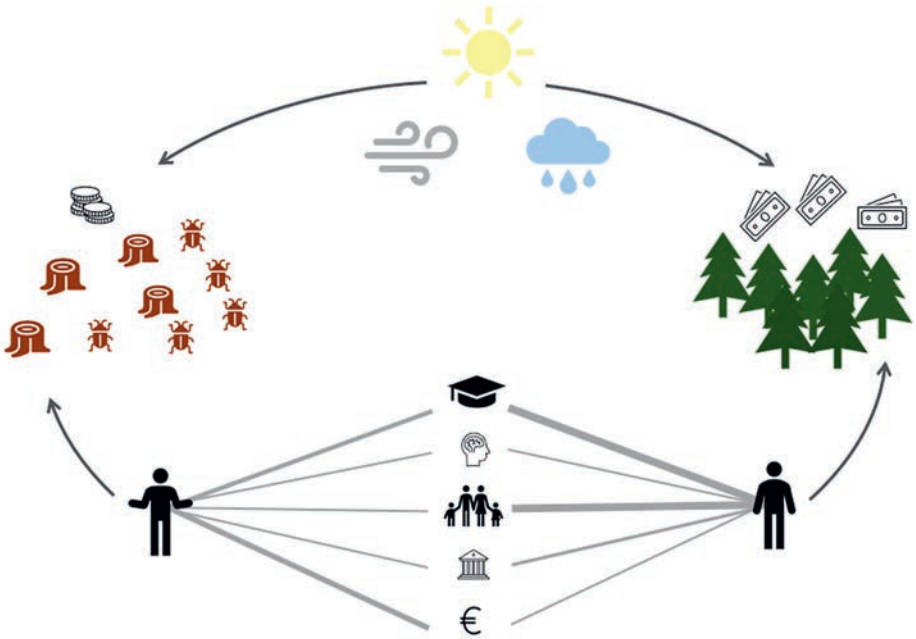
Santa ZELCA[1]*, Ilze VAMZA[2]

[1,2] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia*

* ***Corresponding author.*** *Email address: santa.zelca@edu.rtu.lv*

Abstract – The spruce bark beetle (*Ips typographus*) is becoming an increasingly significant destabilizing factor in forest ecosystems in Northern Europe, including Latvia, under the influence of climate change. The fragmented ownership structure of non-industrial private forests (NIPF) and the action or inaction of forest owners increase the importance of collective action in limiting the spread of the pest. The aim of this study is to analyse the socio-economic impact of the bark beetle on NIPF owners in Latvia and to assess their potential for engagement in risk mitigation. The study is based on a literature review and an online survey (n = 75) comprising 87 structured questions on forest management practices, knowledge level, risk perception, and actual behaviour in the context of bark beetle outbreaks. The data were analysed using descriptive statistics. Although 68 % of respondents report being knowledgeable about the bark beetle issue, preventive action overall remains limited. Among those who had observed damage in their forest stands (49 %), 62 % have taken or plan to take measures, whereas 30 % have not implemented any action. This indicates that direct experience with damage significantly increases the likelihood of action; however, a group of owners with limited response capacity persists even under conditions of direct threat. It can be concluded that NIPF owners' engagement in bark beetle control cannot be explained solely by the level of awareness, but is also related to institutional and motivational factors. Targeted informational support, professional training, and economic incentives may facilitate a shift from reactive to timely and collective action.

Keywords – Bark beetle outbreak; climate adaptation; Non-Industrial Private Forest (NIPF) owners; socioeconomic resilience; sustainable forest governance



The spread of the spruce bark beetle (*Ips typographus*) and socio-economic factors in Latvia's non-industrial private forests: the role of owners in risk mitigation

ACKNOWLEDGEMENT

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ENVIRONMENTAL AND ECONOMIC RATIONALE FOR LATVIA'S PACKAGING DEPOSIT SYSTEM

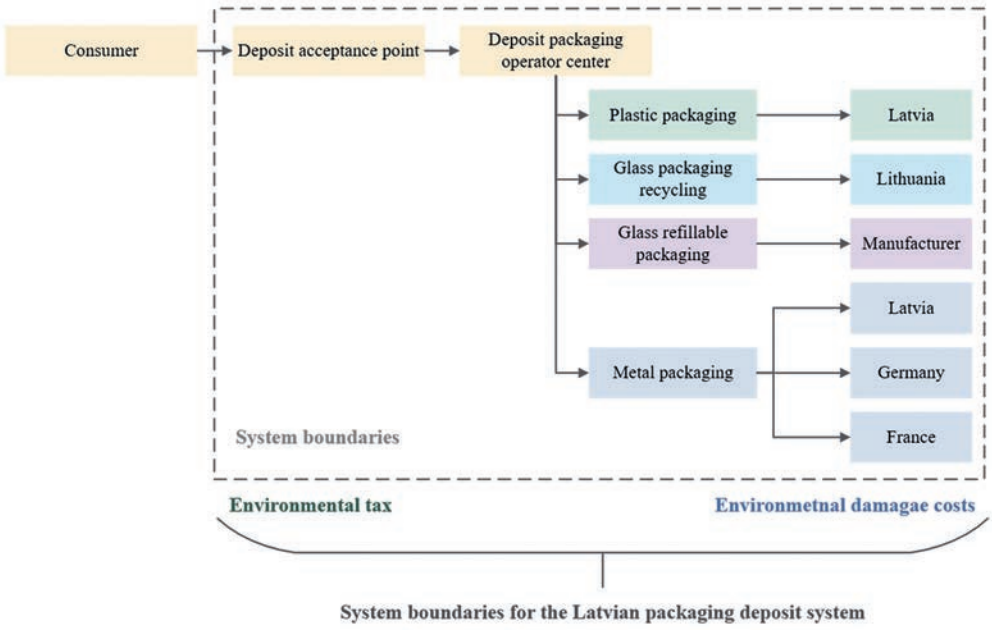
Dace JANSONE-VEVERE[1*], Elina OZOLA[2], Beate ZLAUGOTNE[3], Julija GUSCA[4]

[1–4] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12-k1, Riga, LV-1048, Latvia*

[*] ***Corresponding author.*** *Email address: dace.jansone-vevere@edu.rtu.lv*

Abstract – The packaging deposit system, also known as the deposit refund system (DRS) (also referred to as the deposit return system), aims to reduce waste disposal and promote recycling. The DRS has been introduced in most European countries and demonstrates high effectiveness, as evidenced by high packaging collection rates. In particular, the collection of valuable and recyclable materials is improved, while the environmental impacts and costs associated with the final phase of waste disposal are reduced. However, the overall environmental efficiency of DRS has rarely been analyzed to date, particularly regarding both the positive impacts related to reduced resource consumption and the potential negative impacts arising from system operation, such as the operation of DRS collection points and the transportation of collected packaging waste to recycling plants. Within the present research, the environmental and economic rationale of the Latvian DRS is analysed using a life cycle cost modelling approach, comparing damage costs and the environmental taxes applied to the corresponding packaging. The system boundaries are defined as "gate-to-gate," and the functional unit is 1 tonne of deposit beverage packaging placed on the Latvian market and managed through the deposit packaging system. The system includes the resources required for the operation of deposit packaging collection points, transport to the deposit packaging operator's centre, and transportation to packaging management and recycling sites. The life cycle inventory is based on data collected from DRS operators and other publicly available sources for 2024.

Keywords – Environmental damage costs; environmental tax; packaging



Evaluation framework for environmental and economic rationale of packaging deposit system

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COSTS OF MEETING THE EU'S LULUCF TARGET THROUGH HARVEST RESTRICTIONS

Maarit KALLIO*

Norwegian University of Life Sciences, Faculty of Environmental Sciences and Natural Resource Management, PO Box 5003, N-1432 Ås, Norway

* ***Corresponding author.*** *Email address: Maarit.Kallio@nmbu.no*

Abstract – The EU regulation on greenhouse gas emissions and removals from land use, land-use change, and forestry (LULUCF) is part of the European Union's (EU) 2030 climate change mitigation framework. To meet policy goals, the carbon sinks in managed forests must be enhanced. Owing to the short time span of the policy, reducing roundwood harvests is the only means of substantially contributing to this goal. Enhancing forest sinks in managed forests is often described as a low-cost option for mitigating climate change. Hence, calls to reduce roundwood harvests have increasingly emerged in public debates. However, several studies have indicated that restricting harvests in certain regions is an ineffective policy measure. If harvests in the EU are limited below levels driven by the global demand for wood products, a considerable share of roundwood and forest industry production that would otherwise take place in the EU would be replaced by increased production elsewhere. This study evaluated the costs that could occur if EU Member States restricted their harvests to meet their LULUCF targets instead of following market-driven baseline development. Data on forest sector production were based on recently published simulations using a global forest sector model. A study with leakage mechanisms similar to those in these scenarios suggests that the carbon leakage rate from the EU to the rest of the world (RoW), resulting from environmental policies, would exceed the harvest leakage rate. Therefore, using harvest leakage as a proxy for carbon leakage should not overstate the mitigation costs. Applying national economic multipliers to the change in production in the policy versus baseline scenarios, Germany, France, Finland, and Sweden face the highest costs, amounting to several billions of euros annually in these countries in 2026–2035. A few EU countries gain modestly. The United States, Canada, Brazil, and Russia are the biggest economic gainers. The cautious estimate for the policy costs for the EU countries ranges from 700 €/t CO_2 to 1400 €/t CO_2, depending on whether the decrease in the carbon sink in harvested wood products and the increase in emissions due to a shift toward more carbon-intensive materials are accounted for when calculating the global net change in greenhouse gas emissions. The cost is higher than that associated with many other climate-change mitigation measures. The substantial welfare transfer to the RoW raises the question of whether this policy, which burdens the EU forest bioeconomy, is meaningful.

Keywords – Carbon costs; climate policy; environmental policy; forest sector, harvested wood products; harvest leakage; LULUCF

ACKNOWLEDGEMENT

This work has been supported by the Finnish Forest Foundation within the project "Costs of meeting the EU's LULUCF target through restrictions on forest management".

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DECISION SUPPORT AT THE LOCAL LEVEL: APPLICATION OF SCENARIO ANALYSIS IN CLIMATE POLICY

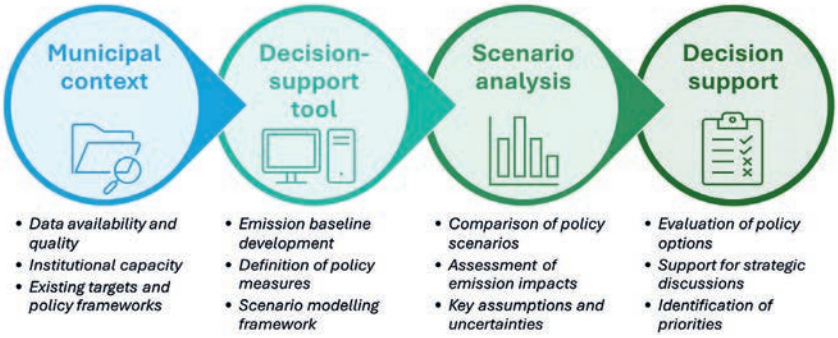
Alina SAFRONOVA[1*], Aiga BARISA[2], Zane PIPKALEJA[3]

[1–3] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, Latvia*

[*] ***Corresponding author.*** *Email address: alina.safronova@rtu.lv*

Abstract – Local governments are essential for reaching climate neutrality goals since they serve as both process coordinators and implementers, as well as public stakeholders. One way to assess the potential impact of various local policy measures is to use the scenario analysis approach. Although it is an important approach for supporting local climate policy decisions, municipalities frequently deal with limited capacity, a lack of data, and complex planning processes; therefore, the practical application of this approach is limited. The study's goal is to investigate how the decision support tool developed as part of the *CommitClimate* project can be used to analyse climate policy scenarios in different municipal contexts. The analysis focuses on using the tool to understand emission sources, study policy scenarios, as well as supporting strategic discussions and development of final planning documents. The paper draws on actual examples from several Latvian municipalities with varying planning experience, institutional context, and data availability. The proposed tool assessed each municipality's emissions in various sectors, including buildings, public infrastructure, waste management, passenger and freight transportation, energy production, and others. The results demonstrated that the proposed decision support tool allows for the identification of municipal development priorities. The comparison of different municipalities, among other things, allowed to identify the main benefits and limitations of using the decision support tool at the local level, as well as the factors that influence its practical application. The study's findings add to the research on local climate management and decision support systems, while also providing practical insights for tool makers and municipalities.

Keywords – Capacity constraints; emissions modelling; local governance; mitigation measures; planning instruments; sustainable energy and climate action plans; SECAP; urban decarbonization



Use of a decision-support tool to support climate policy scenario analysis and strategic decision-making at the municipal level

ACKNOWLEDGEMENT

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IDENTIFICATION OF FACTORS IMPACTING THE USAGE OF URBAN GREEN SPACES: LITERATURE REVIEW AND DELPHI

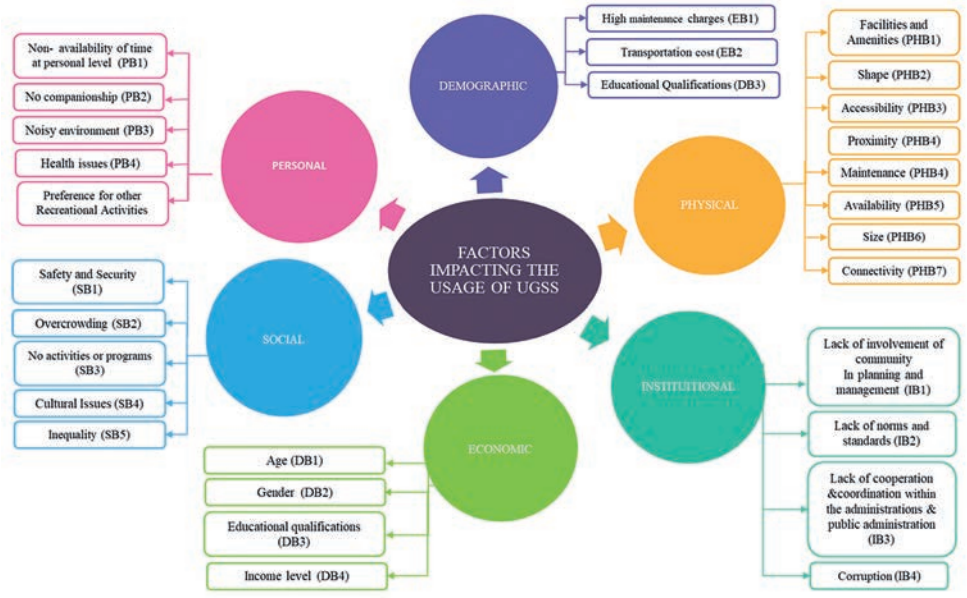
Manoj PANWAR[1]*, Pooja CHAUDHARY[2]

[1,2] *Department of Architecture, Deenbandhu Chhotu Ram University of Science and Technology, Murthal,131039, India*

* ***Corresponding author.*** *Email address: manojpanwar.arch@dcrustm.org*

Abstract – Urban Green Spaces are essential components of the urban system due to their numerous benefits. There are many factors that affect the usage of the Urban Green Spaces. These factors act as barriers or enablers to the usage and significantly contribute to formulating the perception of the benefits. Many scholars, planning organisations, and city administrations have attempted to list this factor. However, the efforts are in bits and pieces, lacking a comprehensive approach. The present study presents a comprehensive list of factors using the established PRISMA technique and two-stage Delphi. The first stage of Delphi helped in the identification, classification, and identification of the direction of causality; and the second stage helped in developing the ranking by using the relative importance indexing method in and among groups. The authors identified 29 factors classified into six categories, along with the direction of causality to usage. The physical factors contribute a maximum of 20.23 %, and demographical factors (10.31 %) have the lowest contribution in factors impacting the usage of UGSs. Transportation cost contributes the highest weight (6.54 %), followed by maintenance charges (5.89 %). The shape of Urban Green Space (1.76 %) influences the users least for their usage, followed by the educational qualification of users (1.77 %). The identified factors, their scoring, direction of causality, and ranking are of high importance for policymakers, planners and urban managers dealing with Urban Green Spaces.

Keywords – Causality direction; policy formulation; PRISMA technique; ranking; urban greens; usage impacting factors



Different types of factors influencing usage of Urban Green Spaces

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ENHANCING TRANSVERSAL COMPETENCIES IN ENVIRONMENTAL ENGINEERING THROUGH INTERDISCIPLINARY LEARNING APPROACHES

Zane PIPKALEJA[1*], Undine GABRANOVA[2], Julija GUSCA[3], Jelena PUBULE[4]

[1–4] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Rīga, LV1048, Latvia*

[*] ***Corresponding author.*** *Email address: zane.pipkaleja@rtu.lv*

Abstract – Environmental engineering studies develop knowledge and skills for solving complex environmental problems, including both in-depth technical knowledge and transversal competencies, including collaboration, communication, critical thinking, problem-solving and time management skills. In the labor market, environmental engineers are increasingly required to work interdisciplinary, collaborating with specialists from various sectors and stakeholders, therefore, it is essential to integrate learning approaches that promote the development of these skills into the study process. Riga Technical University Institute of Energy Systems and Environment implements an interdisciplinary study course (12 ECTS, 40 % of transversal competencies, 60 % technological competencies), within which students apply problem-based learning approach. In the fall semester of 2025, bachelor's students of the study program "Environmental Engineering" addressed a topical sustainable campus challenge – how to improve mobility planning on the RTU student campus in Kipsala neighborhood (Riga, Latvia). The identified mobility problem stems from the goals mentioned in the RTU sustainability strategy and is one of the priorities defined by the RTU administration. The existing problem covers a wide range of stakeholders – RTU employees, students, residents, and visitors, which outlines the complex nature of the problem. During the project, students analysed the existing transport infrastructure, assessed mobility habits, identified key problems, and developed proposals for improving sustainable mobility, presenting the results to a wide range of stakeholders. In this study, based on an online survey (46 students out of 51 course participants responded), an assessment of students' transversal skills development as a result of an interdisciplinary project was conducted. The results of the student survey show that a problem-based and interdisciplinary approach significantly contributes to the development of students' collaboration, communication, analytical thinking and problem-solving skills, as well as improves students' ability to work with real, complex environmental problems. The study confirms the importance of interdisciplinary projects in improving the quality of environmental engineering studies and indicates the need to continue developing similar teaching approaches in higher education.

Keywords – Higher education; learning methods; problem-based learning; sustainable campus; sustainable mobility

The framework of interdisciplinary course in environmental engineering

ACKNOWLEDGEMENT

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URBAN HEAT ISLAND- IMPACTING FACTORS, MEASUREMENT AND MITIGATION MEASURES: SCOPING REVIEW

Manoj PANWAR[1*], Avlokita AGRAWAL[2], Veruval DEVADAS[3]

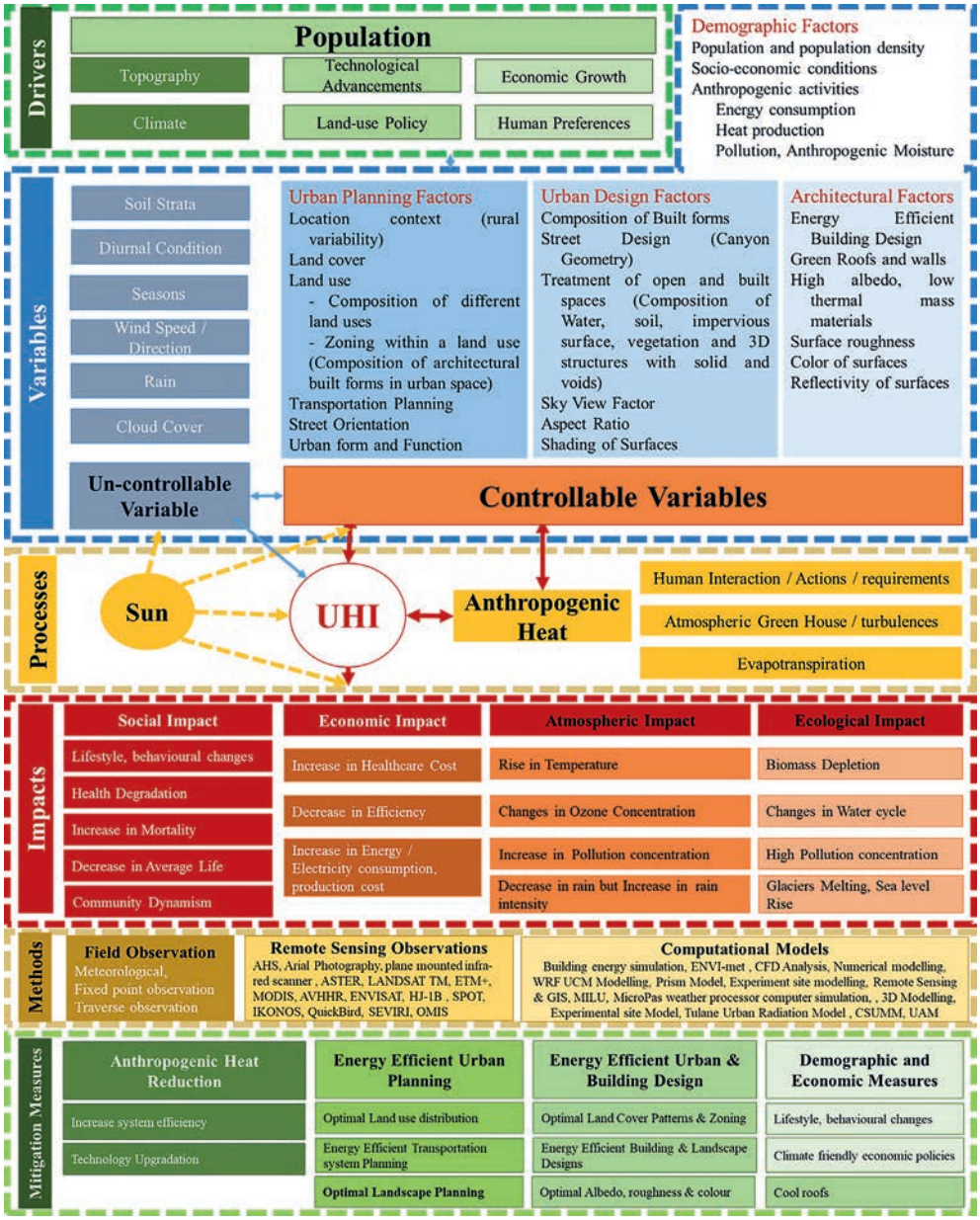
[1] *Department of Architecture, Deenbandhu Chhotu Ram University of Science and Technology, Murthal,131039, India*

[2,3] *Indian Institute of Technology Roorkee, 247667, India*

[*] ***Corresponding author.*** *Email address: manojpanwar.arch@dcrustm.org*

Abstract – Urban settlements are considered as the engine of socio-economic development and have rendered various benefits to human development. Along with numerous benefits, these settlements are disturbing the balance of nature through gradual increase in surface and atmospheric temperature as compared to their surrounding non- urban counterparts, termed as Urban Heat Island (UHI). The objective of this paper is to provide a comprehensive review of factors responsible for proliferation in the temperature in urban areas and mitigation measure purposed by various scholars. The published literature on UHI from 2000 to 2025 has been considered for the study purpose. Literature using keywords UHI, Urban Heat Island, UHI mitigation available online is collected for analysis and then snowball technique is used for identification of important literature. This paper presents account of most noted researches carried out so far in the field of UHI, which will act as library and shall help in guiding future researches and implementation of mitigation measures in the field. The level classification, of factors contributing to UHI and mitigation measures providing relief, is presented first time in literature. The study concludes with the ranked factors and mitigation measures on the basis of their relative importance mentioned in the literature.

Keywords – Mitigation measures; ordered factors and mitigation measures; region-wise; relative order; responsible factors; Urban Heat Island



Drivers, variables, processes, impacts of urban energy interaction in the urban system

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THE LABORATORY OF MAD IDEAS

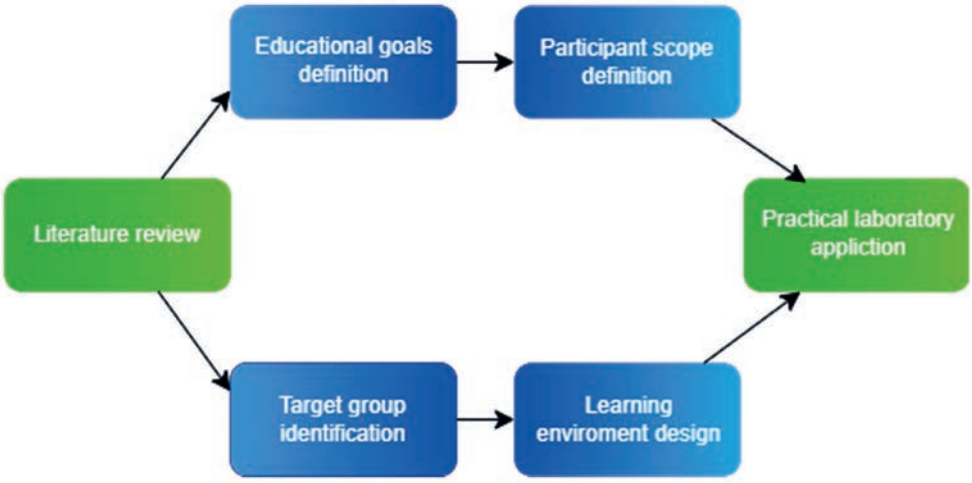
Kristaps KASS[1], Haralds SIKTARS[2*], Vladimirs Kirsanovs[3]

[1–3] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia*

[*] ***Corresponding author.*** *Email address: haralds.siktars@rtu.lv*

Abstract – In recent years, the younger generation in Latvia and Europe has shown more interest in sustainability, climate change mitigation, and environmental protection. However, this interest often remains fragmented and does not integrate into long term engagement with science, technology, engineering, and mathematics (STEM) education. One of the key challenges includes insufficient combinations of formal education style and real-world problem-solving environment, considering technological processes, particularly in the context of relevant word problems, where systemic thinking and practical experience are essential. Experience-based learning and an active educational environment are recognised as effective approaches to strengthening understanding of complex environmental and engineering systems. If integrated with STEM education, the study environment allows learners to engage directly with real processes, experiment with materials and modern technologies, and analyse causality relationships across technological, environmental, and social aspects. This learning approach supports the improvement of engineering thinking by identifying and promoting deeper, more meaningful learning content. "The lab of mad ideas" is an open-type interdisciplinary learning environment developed within the Institute of Energy Systems and Environment at Riga Technical University (IESE RTU). The laboratory is designed as a tool between theoretical education and practical research, offering students and pupils the opportunity to implement experimental projects, develop scientific research work, and explore institute's sustainability-driven activities and goals. In addition, it functions as a transition space between secondary school education and university-level studies, allowing pupils to become familiar with an academic research environment before selecting higher education. The laboratory integrates principles of experimental learning, STEM education, and creative thinking, aligned with the institute's research direction. The proposed laboratory models are based on analysis of successful educational practices and comparable initiatives in European technical universities, highlighting the role of open laboratories and makerspace-type environments in increasing student motivation, interdisciplinary collaboration, and applied research skills. The lab of mad ideas aims to function as a scientifically structured yet flexible platform that supports early engagement in environmental engineering and sustainability topics.

Keywords – Active learning environment; engineering; makerspace-based education; mathematics (STEM); science, secondary-to-higher education transition laboratory; technology



Conceptual structure of "The laboratory of mad ideas."

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HAVE CLIMATE DAYS IMPACTED SOCIETY

Jeļena ZORIČA[1*], Dace PAULE[2], Dagnija BLUMBERGA[3]

[1–3] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia*

[*] ***Corresponding author.*** *Email address: jelena.zorica@rtu.lv*

Abstract – In Latvia, the "Climate Days in Schools" program is one of the major initiatives in climate education that aims to teach students about environmental issues, encourage the use of reliable information sources, and promote environmentally responsible behaviour. However, the factors that determine the program's effectiveness and whether it influences students' behaviour in the long term remain unclear. This research focuses on evaluating the impact of "Climate Days in Schools" on students' attitudes and behaviour, with particular attention to teachers' professional competence and the role of a competency-based education approach. It is assumed that the outcomes of climate education activities are closely connected to teachers' ability to integrate climate issues into the teaching and learning process. This paper is based on a mixed-methods study. The research methods include a review of scientific literature on climate education, the role of teachers, and mechanisms of behavioural change. Empirical data are collected using a survey instrument. The survey is conducted with primary, lower secondary, and secondary school teachers whose students have previously participated in "Climate Days". Several behavioural change indicators are examined, including energy saving, waste sorting, reuse of items, involvement in environmental initiatives, and environmentally responsible daily habits. It is expected that the results of the study will reveal a significant relationship between teachers' professional competence, the implementation of a competency-based approach, and the long-term behavioural changes in students. Based on the findings, proposals for improving "Climate Days in Schools" in Latvia will be developed, including the creation of a regional implementation model and recommendations for providing more examples of effective educational practices. The findings may serve as a foundation for the further development of climate education and for strengthening education policy related to sustainable development.

Keywords – Behavioural change indicators; education for sustainable development; educational innovations in schools; student empowerment; teacher professional competence

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IDENTIFYING BARRIERS TO MUNICIPAL CLIMATE NEUTRALITY: CASE STUDY OF LATVIA

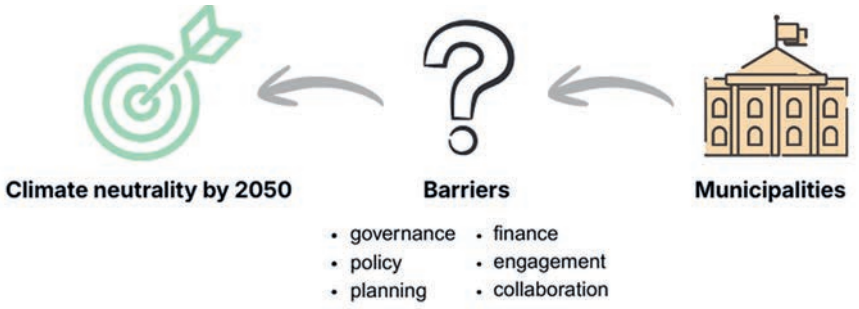
Paula VEINBERGA[1*], Zane PIPKALEJA[2], Aiga BARISA[3], Julija GUSCA[4]

[1–4] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Rīga, LV1048, Latvia*

[*] ***Corresponding author.*** *Email address: zane.pipkaleja@rtu.lv*

Abstract – Local governments play a key role in achieving climate neutrality goals, as the local level is where measures are implemented in the areas of energy management, mobility, territorial development and public services, which directly affect greenhouse gas emissions. The competence of local governments is broad, and although the impact of climate change is evident and the integration of climate goals into regulatory framework is increasing, the prioritization of these topics is not always prominent on the agenda of local governments. However, local government action in the field of emission reduction is often limited by various structural, institutional and practical barriers, the significance and impact of which can vary significantly depending on the local context. This study focuses on the experiences and perspectives of Latvian municipalities on the barriers to achieving climate neutrality, based on the results of a survey of municipalities. The survey serves as the main empirical basis for identifying barriers, assessing their significance and comparing them. The responses provided by municipal representatives allow us to assess which barriers most hinder the implementation of emission reduction measures in practice, as well as to reveal differences between municipalities of different sizes and capacities. The survey results are analyzed in conjunction with existing research on energy management and climate policy implementation in European municipalities, thus providing both an empirical and analytical perspective on the problem. The analytical approach has resulted in conclusions and practical recommendations based on the real needs of local governments, aimed at more effective emission reduction and achieving climate neutrality goals at the local level. The broad scope and mutual influence of barriers shows that transition to climate neutrality is an interdisciplinary issue, in which local governments must be able to apply an integrated approach. At the same time, the results of the study highlight different and divergent experiences of how climate issues are prioritized in local governments, both at the political and management levels – often the prioritization of climate issues among other issues within the competence of a local government is related to the capacity, size and financial capabilities of the local government.

Keywords – Climate strategies; decision-making; GHG emissions; institutional capacity; policy; targeted interventions



Framework for identifying barriers towards climate neutrality in municipalities

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ENERGY CITIZENSHIP IN LATVIA: BRIDGING THE GAP BETWEEN POLICY AND SOCIO-ECONOMIC PRACTICE

Rasa IKSTENA[1*], Ērika LAGZDIŅA[2], Jānis BRIZGA[3], Raimonds ERNŠTEINS[4], Ivars KUDREŅICKIS[5]

[1–5] *University of Latvia, Faculty of Geography and Earth Sciences, Riga, Latvia*
[*] ***Corresponding author.*** *Email address: ri19004@edu.lu.lv*

Abstract – The analysis builds on the conceptual framework developed within the EnergyPROSPECTS project and applies a PESTEL approach to examine the political, economic, social, technological, environmental, and legal conditions shaping energy citizenship at the national level. The study is based on systematic desk research, combining EU-level datasets, national policy and legal documents, official statistics, and survey evidence on household energy practices, socio-economic conditions, and public attitudes. The results show that Latvia has established a broadly supportive policy and legal framework for energy citizenship, including formal alignment with EU energy and climate targets, recent regulatory reforms recognising active consumers and energy communities, and rapid growth in household-level renewable energy adoption, particularly solar photovoltaics. However, this enabling framework predominantly supports individualised and market-based forms of participation. Collective and community-based energy citizenship remains underdeveloped in practice. Key socio-economic constraints limiting broader participation include high energy price volatility, declining household purchasing power during the recent energy crisis, and persistent income inequalities that restrict the capacity of households to invest in energy efficiency and renewable energy technologies. Social factors further constrain engagement, including low levels of climate and energy literacy, limited experience with collective self-organisation, and relatively low public trust in political and administrative institutions. At the local level, constrained administrative capacity and delayed implementation of secondary regulations for energy communities further hinder the translation of formal policy enablement into practice. The Latvian case illustrates a broader challenge in European energy transitions: a gap between the normative promotion of active, collective energy citizenship at the policy level and the socio-economic and institutional conditions that shape citizens' actual opportunities for participation. By explicitly linking national-level PESTEL conditions with observed patterns of energy citizenship, this study contributes to a more differentiated understanding of how energy citizenship is structured, constrained, and realised in practice.

Keywords – Energy citizenship; energy communities; energy transition; EU energy policy; Latvia; PESTEL analysis; socio-economic constraints

ACKNOWLEDGEMENT

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OPERATIONALISING URBAN RESILIENCE ASSESSMENT THROUGH NATURE-BASED SOLUTIONS: A METHODOLOGICAL PROPOSAL

Giulia DATOLA[1], Marta DELL'OVO[2], Alessandra OPPIO[3], Maksims FEOFILOVS[4], Francesco ROMAGNOLI[5*]

[1–3] *Politecnico di Milano, Via Bonardi 3, 20133 Milan, Italy*
[4,5] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia*
[*] ***Corresponding author.*** *Email address: francesco.romagnoli@rtu.lv*

Abstract – The increasing implementation of Nature-Based Solutions (NBS) as strategic interventions to address climate, environmental, and social challenges in urban and peri-urban contexts underscores the urgent need for robust, comprehensive evaluation methodologies to assess the resilience performance resulting from their introduction. While NBS are widely recognised for their capacity to deliver multiple co-benefits, including climate change adaptation and mitigation, enhanced Ecosystem Services (ES), biodiversity conservation, and improved human well-being, their contribution to urban and peri-urban resilience is often assessed in a fragmented, non-standard, or mainly qualitative manner, limiting their effective integration into spatial planning, investment prioritisation, and policy-making processes. Despite abundant literature on the identification and discussion of NBS benefits, significant methodological gaps remain in developing operational, transparent, and replicable evaluation frameworks to support decision-makers and practitioners in systematically designing, comparing, monitoring, and prioritising NBS interventions based on their resilience performance. In this context, the paper provides a comprehensive and critical synthesis of the state of the art in NBS evaluation frameworks, resilience indicators, and decision-support tools, with specific attention to their methodological robustness, scalability, and applicability in urban and peri-urban settings. Building on this review, the study proposes a novel Multiple-Criteria Decision Analysis (MCDA)-based evaluation framework to assess the level of urban resilience enhanced by NBS interventions. The proposed methodology explicitly addresses the multidimensional, systemic, and multifunctional nature of both NBS strategies and the urban resilience concept by structuring interconnected evaluation dimensions encompassing environmental, social, economic, and governance-related criteria. The framework is conceived as a flexible, adaptable tool that supports evidence-based decision-making and enhances the strategic role of NBS in urban resilience-oriented planning processes. The scientific added value of this paper lies in integrating resilience theory with operational MCDA techniques to bridge the gap between conceptual NBS benefits and practical decision-making.

Keywords – Decision support tools; multi-criteria decision analysis; nature-based solutions; resilience assessment; urban resilience

https://doi.org/10.7250/CONECT.2026.099

STRUCTURING BIOMETHANE VALUE CHAINS AS SOCIO-TECHNICAL SYSTEMS: IDENTIFYING GOVERNANCE-RELATED CRITICAL POINTS

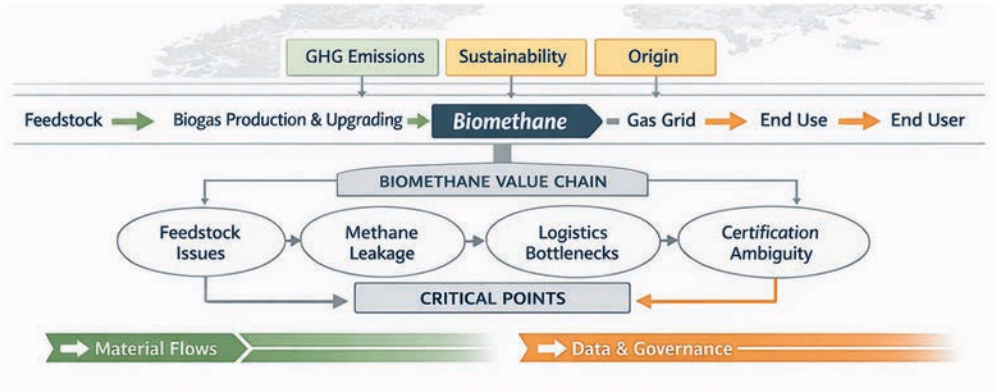
Marta OZOLA[1*], Vladimirs KIRSANOVS[2], Zane KUŠNERE[3]

[1–3] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia*

[*] ***Corresponding author.*** *Email address: marta.ozola.lv@gmail.com*

Abstract – Biomethane is increasingly recognised as a key renewable energy vector in sectors where direct electrification remains technically or economically constrained. Despite technological maturity of anaerobic digestion and upgrading processes, large-scale deployment of biomethane infrastructure often encounters systemic barriers that arise beyond conversion technologies. These challenges emerge across multiple stages of the value chain, including feedstock mobilisation, logistics and scaling, lifecycle greenhouse gas (GHG) accounting, methane emission control, and post-grid-injection verification of sustainability and origin. Such factors influence not only environmental performance, but also institutional credibility and economic feasibility of biomethane projects. This study presents a systematic literature-based conceptualisation of the biomethane value chain extending from feedstock sourcing to final energy use. The research frames the value chain as a socio-technical system in which material flows are accompanied by parallel informational and governance processes related to certification, traceability, and regulatory compliance. Within this framework, the study aims to identify critical control points where interactions between physical production processes and data-driven sustainability requirements affect project viability and market access. The initial analytical application of this framework will focus on the Baltic region, reflecting regional resource availability, infrastructure conditions, and emerging policy implementation practices relevant to biomethane deployment. Particular attention is given to post-grid-injection stages, where biomethane becomes physically indistinguishable from fossil gas and its environmental attributes are allocated through certificate-based mechanisms. In such contexts, interactions between sustainability certification schemes and Guarantees of Origin (GO) systems may introduce ambiguities in attribute ownership and transfer logic, potentially affecting the consistency of environmental claims. By structuring biomethane value chains as integrated socio-technical systems, the study contributes to the development of an analytical foundation for subsequent environmental, economic, and multi-criteria evaluation of biomethane deployment at the municipal level.

Keywords – Baltic region; biomethane value chain; chain of custody; energy governance; Guarantees of Origin (GO); Proof of Sustainability (PoS); socio-technical systems; sustainability certification; value chain assessment



Conceptual Structure of the Biomethane Value Chain as a Socio-Technical System

08

ENVIRONMENT, HEALTH, POLLUTION PREVENTION

https://doi.org/10.7250/CONECT.2026.100

REAL-TIME PREDICTIVE ANALYTICS FOR CATALYTIC CONVERTER HEALTH: A CLOUD-NATIVE IOT APPROACH TO URBAN EMISSION MITIGATION

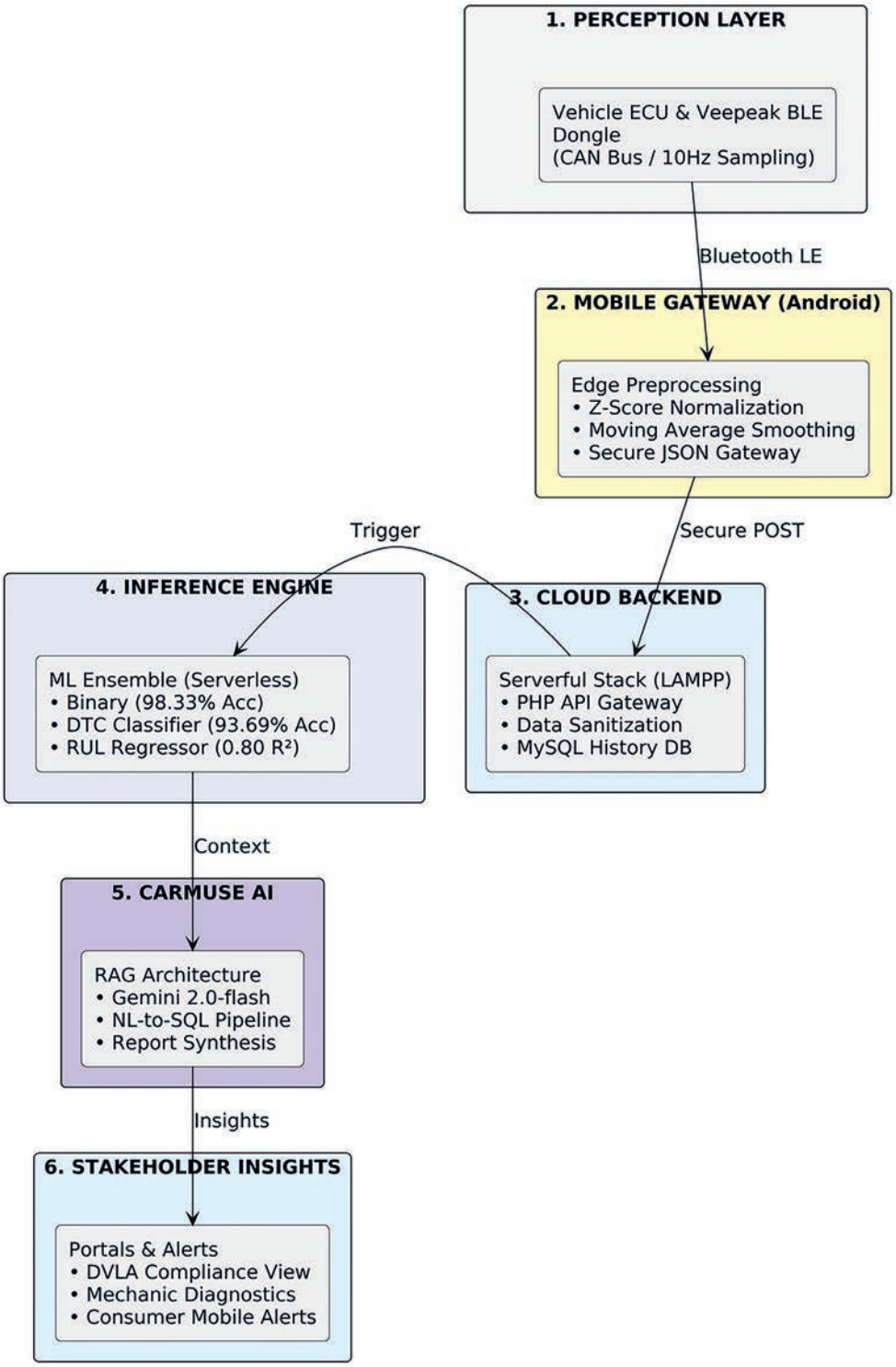
Elikem Asudo Tsatsu Gale-Zoyiku[1*], Pascal Okoli Mathias[2], David Ebo Adjepon-Yamoah[3]

[1–3] *Department of Computer Science, Ashesi University, Berekuso, Ghana*

[*] ***Corresponding author.*** *Email address: egale-zoyiku@ashesi.edu.gh*

Abstract – Vehicular emissions are a primary driver of air pollution in urban centres like Accra, Ghana, where ageing fleets and poor maintenance lead to frequent catalytic converter failure. Real-time monitoring of these components is largely absent in consumer-facing technology, leading to reactive repairs and prolonged environmental impact. This research presents "CatalyticGreat+," an integrated IoT platform for the proactive tracking and predictive maintenance of catalytic converters. The system utilises a Veepeak OBD-II Bluetooth Low Energy (BLE) dongle to capture telemetry from the vehicle's Electronic Control Unit (ECU). Data is processed via a native Android application and transmitted to a hybrid cloud architecture. The backend leverages serverless Google Cloud Functions to host three machine learning models: a binary classifier for fault detection (98.33 % accuracy), a multi-class trouble code classifier (93.69 % accuracy), and an ExtraTrees regression model for predicting Remaining Useful Life (RUL) in hours (R^2 = 0.8061, MAE = 2.22h). A unique contribution of the platform is "CarMuse," a Retrieval-Augmented Generation (RAG) AI that enables non-technical stakeholders, such as DVLA personnel, to query vehicle datasets using natural language. System evaluation under high-load conditions (500 concurrent users) demonstrated a throughput of 82 requests per second with sub-second inference. These results prove that low-cost IoT telemetry and serverless computing can effectively democratize emissions monitoring. This framework provides a scalable roadmap for moving from reactive to predictive maintenance, potentially reducing the collective carbon footprint of urban vehicle fleets in resource-constrained environments.

Keywords – Air quality; catalytic converters; cloud computing; Internet of Things (IoT); machine learning; predictive maintenance; Retrieval-Augmented Generation (RAG)



Hybrid cloud-native architecture for real-time vehicle telemetry and AI-driven predictive maintenance

https://doi.org/10.7250/CONECT.2026.101

INVESTIGATION OF ACOUSTIC–AERODYNAMIC BEHAVIOUR IN A NEWLY DEVELOPED APPARATUS FOR PARTICULATE MATTER AGGLOMERATION

Tautvydas JUKNEVIČIUS[1*], Aleksandras CHLEBNIKOVAS[2]

[1,2] *Vilnius Gediminas Technical University, Saulėtekio al. 11, Vilnius LT-10223, Lithuania*

[*] ***Corresponding author.*** *Email address: tautvydas.juknevicius@vilniustech.lt*

Abstract – With rising air pollution and air quality standards, traditional air-cleaning technologies are becoming outdated as newer technologies emerge. Fine particles size smaller than 2 µm can enter bloodstream through lungs. For these reasons, more research is being conducted on pretreatment technologies. One of the pretreatment technologies is acoustic agglomeration, in which fine particles are combined into larger agglomerates, with help of acoustic waves pressure. This study presents an experimental investigation of the acoustic and aerodynamic parameters of a newly developed agglomeration apparatus designed to enhance the agglomeration of different particulate matter fractions. The aerodynamic performance of the acoustic apparatus was evaluated through measurements of air flow velocity and pressure characteristics with controlled air input and output with the fan and ventilation chamber (air flow sources). Particle agglomeration efficiency was assessed for different particle size fractions ranging from 0.2 µm up to 10 µm. The proposed horizontal acoustic agglomeration chamber incorporates a built-in loudspeaker oriented at a 30° angle relative to the main airflow direction. Experimental tests were conducted under sound pressure levels (SPL) ranging up to 130 dB and across a wide frequency spectrum from 4 kHz to 14 kHz. The results demonstrate that acoustic excitation influences particle interaction mechanisms, leading to enhanced agglomeration for particles under specific operating conditions. The results show that 200–500 nm size particle number decreases while increasing the number of particles in range from 600 nm to 4 µm. The results obtained show that this apparatus is working and it is possible to integrate it as pretreatment technology to other cleaning technologies to increase their efficiency.

Keywords – Acoustic agglomeration apparatus; fine particles; pretreatment technology; sound pressure level

ACKNOWLEDGEMENT

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INTEGRATING LIFE CYCLE ASSESSMENT AND COST ANALYSIS FOR HEALTHCARE WASTE MANAGEMENT IN ULAANBAATAR

Ada CASTELLUCCI[1*], Enkhdul TUUGUU[2], Francesco ROMAGNOLI[3], Luca ADAMI[4], Elena Cristina RADA[5], Gianluca MAGRINI[6], Marco RAGAZZI[7]

[1] *Department of Economics and Management, University of Trento, Via Inama 5, 38122 Trento, Italy*
[2] *Department of Environment and Forestry Engineering, School of Engineering and Technology, National University of Mongolia, Ikh Surguuliin gudamj -1, 14201 Ulaanbaatar, Mongolia*
[3] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia*
[4,7] *Department of Civil Environmental and Mechanical Engineering, University of Trento, Via Mesiano 77, 38123 Trento, Italy*
[5] *Department of Theoretical and Applied Science, University of Insubria, Via G.B. Vico 46, 21100 Varese, Italy*
[6] *Newster System S.r.l., Via Pascoli 26/28, 47853 Cerasolo di Coriano, Rimini, Italy*
[*] ***Corresponding author.*** *Email address: ada.castellucci@unitn.it*

Abstract – The safe, environmentally friendly, and cost-effective management of healthcare waste still remains a major concern for public health and environmental sustainability. Despite recent and ongoing efforts to improve treatment technologies and waste disposal in Mongolia, the current management of the bio-hazardous solid fraction of the healthcare waste in Ulaanbaatar capital city still presents significant room for improvements. As part of an international cooperation project, an electric steriliser based on frictional heat technology was installed in one of the main hospitals in the city to treat the bio-hazardous waste on-site. By using the Life Cycle Assessment (LCA) and cost analysis methodologies, this study aims to evaluate the environmental performance and the costs of two scenarios: the status-quo and the on-site sterilisation. The study combines data from semi-structure interviews and private data collections mainly from one hospital and two companies, with literature and databases. The LCA was conducted in accordance with ISO 14040/44 standards, and the environmental impacts were assessed using the ReCiPe 2016 method implemented in SimaPro based on Ecoinvent v3.9.1 data. The results of the Life Cycle Impact Assessment point out that the on-site sterilisation shows reductions for all the impact categories. The cost analysis encompassed operating, capital and environmental costs. The findings indicated that if the first two are higher for the on-site sterilisation scenario, environmental costs are considerably higher for the off-site treatment scenario, resulting in a total cost increase of only 9 % for on-site treatment when considering a functional unit (FU) of 250 kg of healthcare waste. Finally, the paper highlights the limitations of the applied methodologies in a context of data scarcity and with models based on European or global environmental parameters. The study advocates for greater transparency and accessibility to data when evaluating the impacts of such a potentially hazardous sector, having clear the differences of perspective between global and local environmental impact studies.

Keywords – Bio-hazardous waste; Frictional Heat Treatment (FHT) sterilisation; incineration; sustainability; steam autoclave sterilisation

ACKNOWLEDGEMENT

Thanks to the Ministry of Health of Mongolia, UNICEF Mongolia and Newster Group to have shared the information about the project "Medical Waste Treatment Equipment for Health Facilities in Mongolia" and the selected treatment technology of FHT sterilisation. Thanks to the National Centre for Maternal and Child Health and to Element Medical LCC for sharing data about their facilities. This work has been supported by the PhD Programme SUSTEEMS of the University of Trento.

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INVESTIGATION AND EVALUATION OF THE SOUNDSCAPE OF THE BERNARDINE GARDEN IN VILNIUS

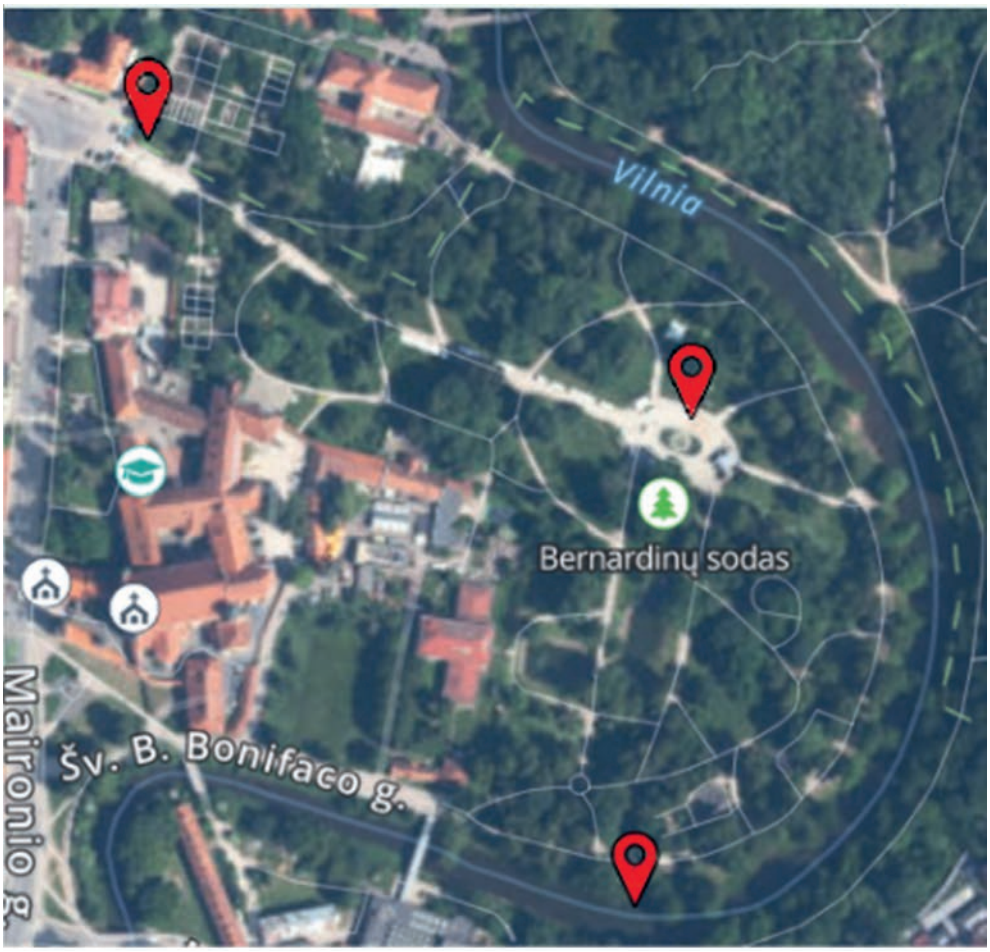
Evelina PETRAUSKAITĖ[1]*, Raimondas GRUBLIAUSKAS[2]

[1,2] *Department of Environmental Protection and Water Engineering, VILNIUS TECH, Saulėtekio al. 11, Vilnius, Lithuania*

* ***Corresponding author.*** *Email address: evelina.petrauskaite@stud.vilniustech.lt*

Abstract – The study and assessment of the acoustic landscape in urban environments is a multifaceted task that requires an understanding of the interaction between sound, space, and human perception. Environmental noise has been recognized as an important form of pollution since the early 1970s and has become an increasingly significant issue with the growth of urbanization. Previous research shows that the acoustic environment can significantly affect human well-being, health, and overall quality of life. While many noise pollution studies focus mainly on objective noise measurements, a comprehensive evaluation of the acoustic environment also requires the inclusion of subjective human perception. Therefore, this study aims to assess the acoustic landscape of Bernardinai Garden in Vilnius by combining objective noise measurements with subjective evaluations obtained through surveys of park visitors. Noise measurements were carried out using a SinusTango^{Plus} sound level meter at several locations within the park at different times of the day, both on weekdays and weekends. Repeated measurements were performed to obtain reliable results and to identify temporal variations in noise levels depending on the time of day and day of the week. The results showed that the highest noise levels were recorded near the main entrance, where urban and traffic noise dominate the acoustic environment. The fountain area was characterized by a mixed acoustic environment in which the artificial sound of water significantly influenced the frequency spectrum and partially masked other environmental sounds. The quietest acoustic environment was identified near the Vilnelė River, where natural sounds prevail and the influence of human activity is lower. Across all three measurement locations, the maximum sound level (L_{AFmax}) ranged from 57.9 to 82.9 dB, resulting in an overall difference of about 25 dB. Meanwhile, the equivalent sound level (L_{Aeq}) varied from 43.8 to 67.0 dB, indicating a difference of approximately 23 dB between locations and measurement periods. Overall, the results show that both noise intensity and its spectral structure vary depending on spatial characteristics and prevailing human activities within the park. Survey results indicate that the acoustic environment is most often perceived as calm and pleasant; however, some respondents also described it as noisy or irritating. This suggests that the perception of the soundscape may vary depending on the time of day or the specific location within the park. The findings highlight the importance of integrating both objective measurements and subjective perception when assessing and managing urban acoustic environments.

Keywords – Human perception; noise pollution; soundscape, subjective and objective assessment; urban environment



Study area with marked measurement points (at the main entrance, near the fountain, and by the river)

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REMOTE SENSING ASSESSMENT OF LAND SURFACE TEMPERATURE AND VEGETATION COOLING IN VILNIUS, KAUNAS AND KLAIPĖDA

Adas PRANCKEVIČIUS[1]*, Aušra ZIGMONTIENĖ[2]

[1,2] *Department of Environmental Protection and Water Engineering, Vilnius Gediminas Technical University, Saulėtekio al. 11, Vilnius Lithuania*

* ***Corresponding author.*** *Email address: adas.pranckevicius@stud.vilniustech.lt*

Abstract – Urbanisation in many parts of Europe is still ongoing, and as cities continue to expand, natural surfaces are increasingly being replaced by artificial materials, which absorb and retain heat more effectively than vegetation. This intensifies surface heating, increases thermal stress and creates challenges for public health, energy demand and climate adaptation. European Green Deal, EU and national climate adaptation strategies emphasize the need for evidence-based approaches to cooling and green infrastructure. The aim of this study is to assess surface thermal patterns and vegetation related cooling in Vilnius, Kaunas and Klaipėda municipalities using remote sensing data, and to evaluate how local changes in tree cover density impact the cooling effect in different city neighbourhoods. Landsat 8/9 data were used to calculate and map warm season baseline and heatwave land surface temperature, while tree cover density was characterised using Copernicus HRL Tree Cover Density product. Tree related cooling was estimated by modelling the relationship between land surface temperature and tree cover density for each city. In selected city neighbourhoods, increased and reduced tree cover scenarios were applied to determine how changes in tree cover density affect the cooling of surrounding areas. Vilnius is the most vegetation dominated city, with trees covering 57.6 % of the municipal area, while Kaunas has the highest built-up surface share (33.3 %). Accordingly, warm season baseline land surface temperature was highest in Kaunas (28.3 °C), average temperature in Vilnius and Klaipėda was 1.5 °C and 2.0 °C lower, respectively. During heatwaves, average land surface temperature was up to 10 °C higher compared to baseline conditions. Tree cover related cooling was strongest in Vilnius, where mean modelled cooling reached 2.2 °C under baseline conditions and 2.3 °C during the heatwave case, compared with 1.1–1.3 °C in Kaunas and 0.7–1.1 °C in Klaipėda. Scenario analysis in selected neighbourhoods showed that reduction of around 50 % in tree cover density caused local losses of cooling reaching up to 4.9 °C in the area where changes were made, while the same increase strengthened local cooling by up to 2.9 °C. At neighbourhood scale, the effect was smaller, typically within about 0.1–0.6 °C, however the modified sites represented only about 7 % of the wider neighbourhood areas. The results show that this approach can support urban planning aligned with climate adaptation by helping to understand how changes in tree cover influence the local cooling effect.

Keywords – Heat mitigation; thermal stress; tree cover density; urban climate

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ASSESSMENT OF QUIET AREAS IN VILNIUS CITY AND MODELLING OF NOISE MITIGATION MEASURES

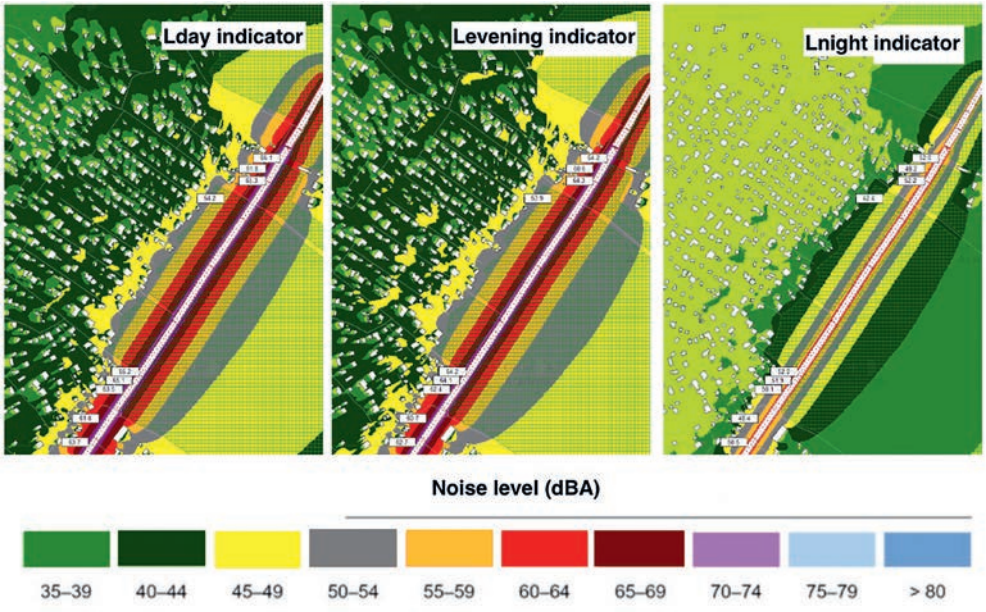
Erika ČAPLIKAITĖ[1*], Raimondas GRUBLIAUSKAS[2]

[1,2] *Department of Environmental Protection and Water Engineering, Vilnius Gediminas Technical University, Sauletekio al. 11, Vilnius Lithuania*

[*] ***Corresponding author.*** *Email address: erika.caplikaite@stud.vilniustech.lt*

Abstract – Environmental noise is a major environmental stressor impacting human health and quality of life in cities. According to the European Environment Agency, environmental noise is the second most harmful environmental factor in Europe after air pollution. Continuous exposure to excessive noise levels contributes to adverse health effects such as sleep disturbance, cardiovascular diseases, and increased stress levels. In urban environments, quiet areas play an important role in improving public well-being by providing spaces with lower noise exposure suitable for recreation and relaxation. In Vilnius, quiet areas are defined as territories where environmental noise levels should not exceed Lnight (night-time noise indicator) 50 dBA, yet some designated areas are currently exposed to higher noise levels due primarily to road traffic. The aim of this study was to analyse quiet areas in Vilnius city and to evaluate the effectiveness of potential noise mitigation measures through acoustic modelling. Noise propagation modelling was carried out using the CadnaA software to simulate road traffic noise distribution under different scenarios. The modelling incorporated traffic intensity data, spatial characteristics of the urban environment, and environmental parameters. Additionally, potential reductions in health impacts were evaluated using the Disability-Adjusted Life Years (DALY) approach. The modelling results showed that road traffic is the dominant noise source affecting the analysed quiet areas. In several locations the predicted noise levels exceeded the recommended Lnight 50 dB threshold for quiet areas. Scenario simulations demonstrated that targeted mitigation measures, such as traffic flow management, installation of noise barriers, and the use of green infrastructure, can significantly reduce noise exposure in these areas. The results indicate that integrating acoustic modelling into urban planning can effectively support the protection and improvement of quiet areas. The study demonstrates that the implementation of appropriate mitigation measures can reduce environmental noise levels and contribute to healthier and more comfortable urban environments.

Keywords – Acoustic environment; CadnaA (Computer Aided Noise Abatement); Disability-Adjusted Life Years (DALY); environmental acoustics; road traffic exposure; urban planning



Modelled road traffic noise levels for Lday, Levening and Lnight indicators under baseline conditions

09

WASTE. WASTE TO PRODUCT, VALUE ADDED PRODUCTS

https://doi.org/10.7250/CONECT.2026.106

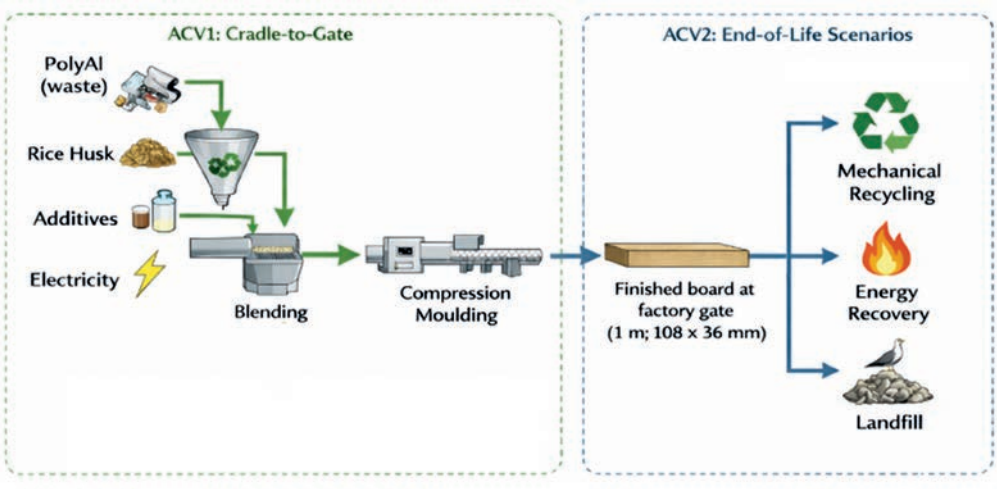
LIFE CYCLE ASSESSMENT OF RECYCLED POLYAL–RICE HUSK BOARDS FOR URBAN FURNITURE

Alba LORIENTE[1*], M.A PEREZ PUIG[2], Fidel SALAS[3], Oscar LORIENTE[4]

[1] *Universitat Politècnica de València (UPV), Camino de Vera, 46022, Valencia, Spain*
[2–4] *Department of Mechanical and Materials Engineering, Universitat Politècnica de València (UPV), Camino de Vera, 46022, Valencia, Spain*
[*] ***Corresponding author.*** *Email address: lorientealba@gmail.com*

Abstract – Multilayer beverage cartons and rice husk represent two abundant waste streams with significant yet underutilised potential in circular-economy applications. This work presents a life cycle assessment (LCA) framework for wood-like composite boards manufactured in Valencia (Spain) using 70 wt.% recycled PolyAl from beverage cartons and 30 wt.% ground rice husk. The boards are produced through blending, extrusion and compression moulding, yielding prismatic profiles with an approximate 108 × 36 mm cross-section and lengths up to 3 m. The study is designed as a cradle-to-gate assessment (ACV1) to quantify the environmental impacts of manufacturing the boards and to identify process hotspots. The functional unit is defined as 1 m of finished board at the factory gate (108 × 36 mm). The PolyAl fraction is modelled using a cut-off approach, treating it as a waste-derived input and accounting for impacts from collection/handling and transport to the manufacturing site onwards. Modelling is conducted in openLCA using the Environmental Footprint method (EF 3.1) for impact assessment; background processes such as electricity supply, transport and end-of-life treatments are represented using recognised LCA datasets. In addition, an end-of-life scenario block (ACV2) is included to explore the sensitivity of results to alternative waste management routes for the board, namely mechanical recycling, energy recovery and landfill. The scenario analysis is intended to assess how strongly the overall environmental profile depends on disposal assumptions and to support decision-making for scalable waste-valorisation pathways. The results include quantified impact indicators per functional unit, a contribution analysis distinguishing the role of electricity demand in extrusion and compression moulding versus material inputs and transport, and a comparative evaluation of alternative end-of-life scenarios. The work provides an initial, transparent environmental baseline to complement prior mechanical characterisation and to guide future optimisation and scale-up of waste-based composite boards for low-load urban furniture and related outdoor applications.

Keywords – Circular economy; end-of-life scenarios; environmental Footprint (EF 3.1); extrusion; hotspot analysis; material recycling; resource recovery; waste valorisation



System boundaries and end-of-life scenarios of the assessed board

ACKNOWLEDGEMENT

The authors would like to thank the laboratory technicians of the Materials and Mechanical Testing Laboratory at the Universitat Politècnica de València for their technical support during the experimental characterisation of the waste-based composite material. The authors also acknowledge the industrial partner involved in the valorisation of PolyAl and rice husk residues, which enabled the development and assessment of the composite boards analysed in this study.

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VALORISATION OF MIXED POST-CONSUMER TEXTILE WASTE THROUGH MYCELIUM-BASED MATERIALS

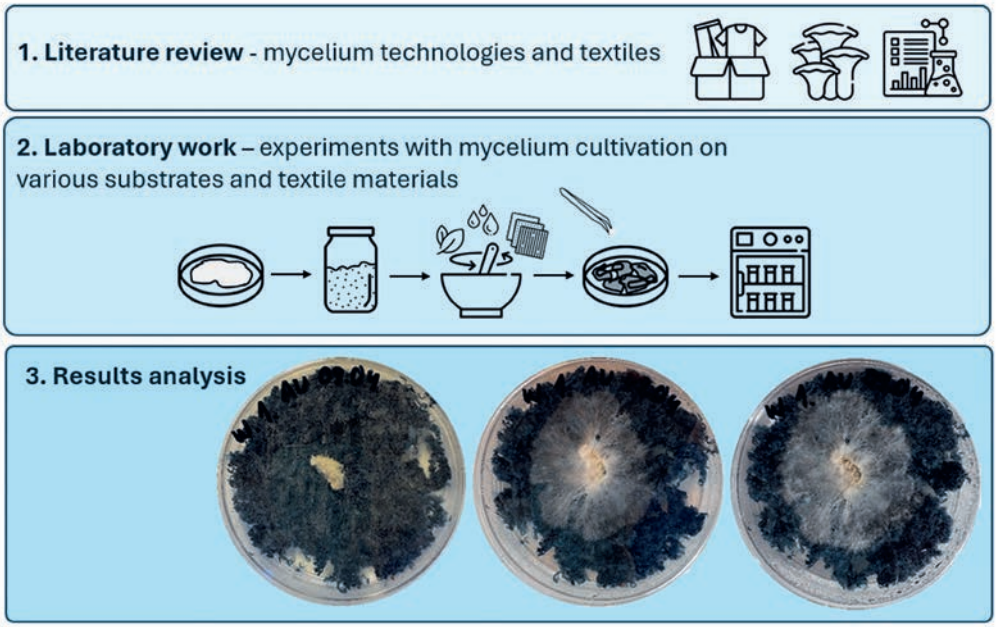
Megija VALTERE[1*], Tereza BEZRUCKO[2], Ilze VAMZA[3], Dagnija BLUMBERGA[4]

[1–4] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, LV-1048 Riga, Latvia*

[*] ***Corresponding author**. Email address: megija.valtere@rtu.lv*

Abstract – The circularity of textiles is currently a very pressing issue, as consumption of textiles continues to grow, and with it the amount of waste, of which only around 25 % is recycled. Solutions are being developed across the entire value chain to implement a circular economy, from eco-design to recycling of post-consumer waste. However, research on the recycling of mixed post-consumer textiles into textiles or products with higher added value is limited. The authors have previously conducted a literature review to identify recycling solutions for mixed post-consumer textile waste and to assess their development potential. The results of comparing several products showed that mycelium material has the greatest potential. Mycelium has long been used in medicine and the food industry, but over the last two decades, new applications for it have been developed in materials science. The mycelium technologies are becoming increasingly attractive because these materials exhibit good technical properties, cost-effectiveness, and low environmental impact. To the best of the author's knowledge, only five studies have so far been carried out on growing mycelium on textile alone or on textile and biomass together, and three of these have successfully led to the development of a mycelium-based composite on a lab scale. Therefore, this study aimed to summarize previous research findings on textile and mycelium and to conduct laboratory experiments to determine the most suitable biomass and textile combination, as well as the most suitable mushroom strain. Experiments were conducted with four mushroom species, two popular and two previously unused in mycelium technology research. Several lignocellulose residues were tested as substrates, with the prospect of finding high-value applications for these residues. Mixed post-consumer textile waste was used as the textile input. The results confirm that textile waste that cannot be recycled back into textile products has potential for use in mycelium-based materials.

Keywords – Circular economy; fungi; mycelium technologies; textile recycling



The methodology framework for the study

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WHEN BIOREMEDIATION MEETS CIRCULAR ECONOMY: VALORIZATION OF ORGANIC WASTES FOR ENHANCED REMEDIATION OF HYDROCARBON-CONTAMINATED SOILS

Andrea FRANZETTI[1*], Asia ROSATELLI[2], Davide ROSSI[3], Alessandra SUAGHER[4], Mentore VACCARI[5], Teklit GEBREGIORGIS[6], Alif CHEFFI[7], Silvia SBAFFONI[8], Tiziana BELTRANI[9]

[1–4] *University of Milano-Bicocca, Department of Earth and Environmental Sciences (DISAT), Milan, Italy*
[5–7] *University of Brescia, Piazza del Mercato, 15, 25121 Brescia BS, Italy*
[8,9] *ENEA C.R. Casaccia, Via Anguillarese, 301, 00123, Rome, Italy*
[*] ***Corresponding author.*** *Email address: andrea.franzetti@unimib.it*

Abstract – The integration of biological treatment strategies with circular resource management offers a sustainable solution for restoring hydrocarbon-contaminated land while simultaneously valorizing organic residues. This study evaluates the performance of waste-derived amendments – including biochar, rhamnolipid biosurfactants, compost, and digestate – in enhancing biological and bioelectrochemical degradation processes. Laboratory and pilot-scale experiments were conducted to assess contaminant removal, electrochemical activity, and shifts in microbial community structure. Biochar obtained from biomass pyrolysis was tested as a conductive soil amendment in microbial electrochemical systems. An optimized dose of 8 % (w/w) resulted in hydrocarbon removal efficiencies up to 87.8 % and a maximum current density of 3.5 A/m^2, demonstrating improved extracellular electron transfer. Higher biochar concentrations reduced performance, likely due to mass-transfer limitations and decreased abundance of electroactive genera such as Geobacter and Desulfuromonas. Rhamnolipid biosurfactants produced from organic waste substrates were applied to increase contaminant bioavailability. A concentration of 100 mg/L enhanced removal to 72.5 % and increased current output ninefold compared with untreated controls, alongside enrichment of electroactive and hydrocarbon-degrading microbial taxa. A sequential treatment combining electro-Fenton oxidation with a rhamnolipid-assisted bioslurry phase was also investigated. Electrochemical oxidation using boron-doped diamond electrodes achieved 70.6 % degradation and generated more biodegradable intermediates, which were subsequently mineralized during the biological phase, leading to an overall removal of 93.6 % within 72 hours. These findings demonstrate that materials derived from organic waste streams can significantly intensify remediation processes while contributing to resource recovery and waste reduction. Optimization of amendment dosages, reduction of energy demand, and validation at field scale are key steps toward practical implementation.

Keywords – Anodic Biofilms; electrochemical oxidation; environmental restoration; Microbial Electrochemical Technologies (MET); resource recovery; rhamnolipid; waste-derived amendments

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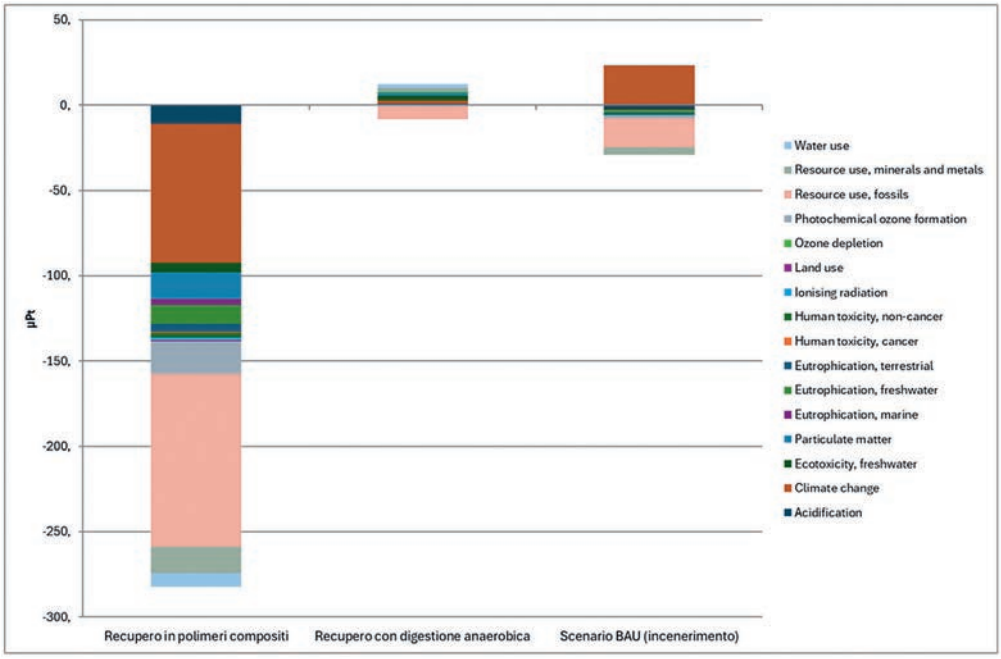
LIFE CYCLE ANALYSIS OF MATERIAL AND ENERGY RECOVERY FROM WIRE DRAWING LUBRICANT WASTE

Valentina CASTELLANI[1], Asanka ILLANKOON[2], Elena COLLINA[3], Valeria MEZZANOTTE[4*]

[1] *LCA consultant, Milano, Italy*
[1–4] *Università di Milano-Bicocca, DISAT, Piazza della Scienza 1, 20126 Milano, Italy*
[*] ***Corresponding author.*** *Email address: valeria.mezzanotte@unimib.it*

Abstract – In the framework of the STAR project, the valorisation of stearate based solid lubricant waste from wire drawing process was investigated with respect to material recovery (addition in polymeric matrices) or energy recovery (anaerobic digestion with biomethane production). The aim of the present study is to compare different scenarios for the treatment or recovery of wire drawing lubricant waste (WDW) in order to identify the best option from an environmental point of view. The study was conducted using the Life Cycle Assessment (LCA) methodology. The functional unit considered was "treatment or recovery of 1 kg of WDW". The impacts of three scenarios were compared: 1. Business As Usual (BAU): WDW incineration with energy recovery; 2. Material recovery in the production of LDPE-based composite polymers; 3. Anaerobic digestion of WDW, with biogas production and its conversion to biomethane. In all scenarios, the process that generated the waste was excluded, while credits associated with avoided products were included. The Life Cycle Inventory model was created in the Simapro 10.2 software. The impact calculation was carried out using the EF 3.1 method. The scenario that guarantees the greatest benefit in terms of avoided impacts is scenario 2 (–282.22 µPt) (figure). The other two scenarios have much lower values: –5.58 µPt for the BAU scenario and 4.37 µPt for the anaerobic digestion scenario. This result strongly depends on the assumptions regarding the polymer substitution rate (1 kg of LDPE avoided for every kg of WDW recovered) and methane production rate (0.22 m^3 of fossil methane avoided for every kg of WDW recovered) and may vary, in case more specific values become available in the future.

Keywords – Anaerobic digestion; environmental footprint; wire drawing lubricant; waste recovery



Comparison between the analyzed scenarios (results of the weighing phase)

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MUNICIPAL WASTEWATER SLUDGE HYDROTHERMAL CARBONISATION AS A TOOL FOR REMOVAL OF EMERGING POLLUTANTS

Lauris ARBIDANS[1*], Yelyzaveta VIVDENKO[2], Jorens KVIESIS[3], Linda ANSONE-BERTINA[4] Maris KLAVINS[5]

[1–5] *Department of Environmental Science, University of Latvia, Jelgavas iela 1, Riga, LV 1004, Latvia*

[*] ***Corresponding author.*** *Email address: lauris.arbidans@lu.lv*

Abstract – Municipal wastewater sludge is a challenging residue due to high moisture content, heterogeneous composition, presence of nutrients, potentially toxic elements and emerging pollutants like pharmaceutically active substances. Current solutions in handling this waste are by composting, which is time consuming and generates greenhouse gases in the process; pyrolysis, which requires energy-intensive pre-drying; used in agriculture as fertilizer, which raises concerns of potential pollutant leaching in the soil. Hydrothermal carbonization (HTC) offers a route to convert wet sludge into a carbon-rich solid hydrochar under moderate temperatures of 160–250 °C and pressures up to 10 bar, supporting circular-economy solutions for sludge management. In this work, the influence of HTC temperature and residence time on hydrochar yield, process water chemistry, hydrochar thermal stability, element partitioning assessment in both hydrochar and process water using municipal sludge from Latvia. Dewatered sludge was collected in autumn 2025 from SIA "Ūdeka" wastewater treatment facilities (Ventspils, Latvia), dried at 105 °C. HTC was carried out in 100 mL PTFE autoclaves using dried sludge and deionized water at 170, 200 and 230 °C for 0.5, 1, 3 and 6 h as process optimization matrix parameters. After cooling and filtration, hydrochar yield was assessed, liquid-phase pH and electrical conductivity were measured, hydrochars were characterized by TGA/DTG, element concentrations were quantified by ICP-OES in both solid and liquid fractions. Residual pharmaceuticals (ibuprofen, progesterone) were quantified in the liquid phase and hydrochar extracts using UHPLC equipped with photodiode array (PDA) and fluorescence (FLR) detectors, enabling temperature-dependent degradation profiles. Increasing process severity decreased hydrochar yield, indicating intensified hydrolysis/solubilization: the maximum yield (87 %) was obtained at 170 °C/0.5 h, while yield dropped to 58 % within the 170 °C series at 6 h and to 52 % across the full experimental matrix at the most severe conditions. TGA-based proximate indicators showed progressive solid-phase stabilization, while volatile matter decreased from 67.90 % (raw sludge) to 42.19 % (230 °C/3 h), while ash increased from 22.06 % to 46.87 %. Element analysis demonstrated strong retention in hydrochar and limited transfer to process water; phosphorus reached 36,118 µg/g in hydrochar at 200 °C/3 h, highlighting nutrient-recovery potential, while several metals in the liquid phase were below quantification limits. Pharmaceutical degradation parameters were assessed.

Keywords – HTC; hormones; pharmaceuticals; phosphorus; valorisation

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BLIND SPOTS IN BIOECONOMY POLICY PLANNING IN LATVIA: THE FISHERIES AND AQUACULTURE SECTOR

Ilze BALCERBULE[1*], Krista LAKTUKA[2], Dace LAUKA[3]

[1–3] *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia*

[*] ***Corresponding author.*** *Email address: ilze.balcerbule_1@edu.rtu.lv*

Abstract – Aquaculture, which is the specialized breeding or cultivation of fish and other aquatic organisms in inland and marine waters, opens up opportunities for bioeconomy growth in Latvia, while reducing environmental pollution, promoting the production of nutrient-rich food and contributing to the preservation of ecosystems and biodiversity. The potential of aquaculture in Latvia has not been fully realized, despite the implemented bioeconomy policy and significant investments from the European Maritime, Fisheries and Aquaculture Fund. However, it is developing as a rapidly growing, productive and competitive fisheries sub-sector worldwide. The aim of the study is to identify and analyze factors that limit the development potential of aquaculture in Latvia, evaluating the bioeconomy policy for the period from 2014 to 2027, its effectiveness and sustainability, as well as revealing shortcomings or blind spots in policy planning and implementation. The study identifies the main barriers to the development of the sector and identifies possible policy improvement instruments. The study draws on a wide range of literature on good governance practices and strategic risks in bioeconomy policy planning. It also includes a survey of Latvian aquaculture companies, which combines closed and open-ended questions with in-depth interviews. These are used to assess the current problems, needs and risks related to the development of the sector. The study is significant because it can serve as support for bioeconomy policymakers and aquaculture sector developers, providing a practical guide for effective policy analysis with key performance indicators (KPIs) for assessing the development of the sector. The study also includes recommendations on long-term measures to be implemented to promote the development of fisheries and aquaculture in Latvia.

Keywords – Aquaculture; bioeconomy policy; fisheries; policy planning; sustainability

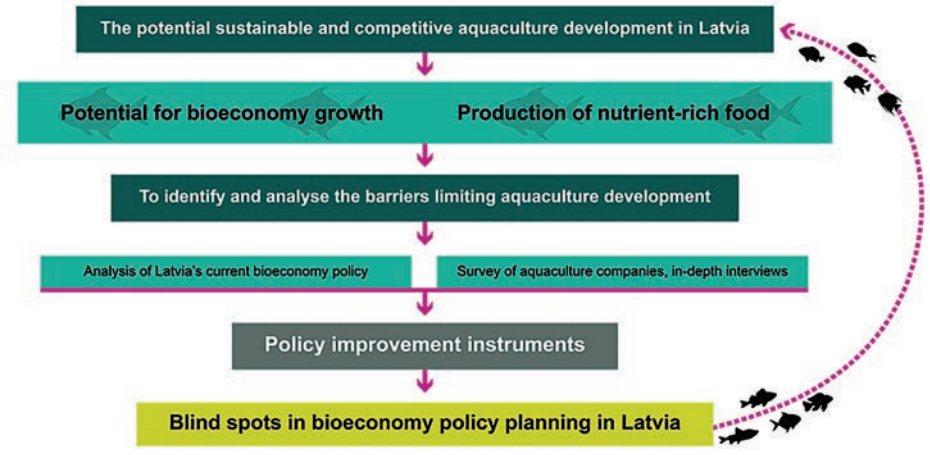

Fig. 1. Progressing towards sustainable aquaculture

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EXPLAINABLE MACHINE-LEARNING MODEOPTIMIZED USING FORWARD FEATURE SELECTION ALGORITHM FOR PREDICTION OF GROUND OZONE CONCENTRATION

Ibrahim KHALIL UMAR[1*], Samir BASHIR[2]

[1] *Department of Civil and Engineering, Federal University of Technology, Babura Jigawa, Nigeria*
[2] *Department of Civil and Engineering Technology, Kano State Polytechnic, Kano*
[*] ***Corresponding author.*** *Email address:ikumar.civil@futb.edu.ng*

Abstract – An accurate model for prediction of air quality parameters such as ground ozone (o3) serves as policy and decision-making tool for providing healthy and friendly environment. in this study, six machine-learning models (neural network (nn), ensemble, kernel regression, regression tress, support vector regression (svr), and multilinear regression (mlr)) were developed for prediction of ground ozone concentration using 35 065 hourly data from January 2013 to february 2017. The selection of relevant input variables for the models was using forward feature selection algorithm. the forward feature selection reveals rain, day and wind speed as the least important variable for the prediction of ozone concentration. the models were evaluated using mean absolute error (mae), mean square error (mse), root mean square error (rmse) and nash sutcliffe efficiency (nse) in both training and testing stage. the nn model outperformed ensemble, kernel, tree, svr and mlr by 0.73 %, 4.74 %, 6.47 %, 11.41 % and 25.17 % respectively in the testing stage. copland algorithm inicates the nn model as the overall best model considering all evaluation metrics. the shapley analysis indicates temperature, nitrogen oxide and hour of the day as the major factors contributing to ground ozone concentration.

Keywords – Ground ozone, neural network, machine learning, forward feature selection

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