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# **Sustainable Built Environment and Energy Transition (SBEET)**

11-12 February

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**Sustainable Built Environment and Energy Transition (SBEET)**

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## Urban Building Energy Modelling of Residential Heating and Cooling Demand under Climate Change Insights from Two Nordic Cities Växjö Sweden and Bærum Norway

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### Abstract

Residential buildings are central to Europe's energy transition as climate change alters heating and cooling demand and increases risks related to thermal discomfort. In Sweden single family houses account for approximately 43 percent of the building stock and 40 percent of residential energy use while in neighboring Nordic countries demographic ageing increases the importance of ensuring adequate thermal comfort in elderly housing. Understanding how future climate conditions affect residential energy demand across different residential typologies and urban contexts is therefore essential for building and energy system planning.

This study applies Urban Building Energy Modelling to examine future residential energy demand and thermal comfort under climate change through two parallel studies conducted in Nordic cities. The first study analyses district heated single family houses in Växjö Sweden represented by two villas and two townhouses. The second study focuses on newly built elderly housing in Baerum Norway. Both studies use a Python based UBEM framework with EnergyPlus as the simulation engine and are driven by consistent climate scenario assumptions. Future climate impacts are evaluated using Representative Concentration Pathway scenarios RCP 2.6 RCP 4.5 and RCP 8.5 across midcentury time horizons. Baseline simulations rely on local measured weather data and Typical Meteorological Year files while future typical and extreme weather datasets are generated using Meteororm version 8.1. Model calibration and validation are conducted using measured energy data where available.

Results from both cities are analysed simultaneously at monthly and hourly resolutions to assess seasonal energy demand shifts and changes in peak loads. Across both residential typologies heating demand consistently declines while cooling demand and peak cooling events increase under higher emission scenarios. However, the magnitude and timing of these changes differ between single family housing and elderly housing reflecting differences in building design occupancy patterns and thermal sensitivity.

The findings demonstrate how Urban Building Energy Modelling enables cross context interpretation of future residential energy demand and provides evidence to support HVAC design district heating planning and policies addressing thermal comfort in Nordic cities.

## Reducing Residential Building Energy Demand through Passive Design and Retrofitting

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### Abstract

Rapid urbanization in low- and middle-income countries has resulted in a substantial increase in residential building energy demand, with Nepal experiencing similar trends. This study evaluates the effectiveness of passive design strategies, focusing on the application of thermal insulation materials and double-glazed windows, in comparison with typical non-insulated, single-glazed reinforced cement concrete (RCC) frame buildings with brick infill and cement plaster commonly found in the Kathmandu Valley, Nepal. Kathmandu's climate is characterized by average temperatures of approximately 10 °C in winter (January) and 23 °C in summer (August). Using EnergyPlus simulations, the performance of locally available insulation materials, particularly expanded polystyrene (EPS), is assessed. The result indicates that heating accounts for 74% of the total annual building energy demand, while cooling represents the remaining 26%. The integration of 50mm EPS insulation on walls and roofs, together with double-glazed windows in a typical building, results in a significant reduction of the building's thermal load. Based on these findings, the study recommends prioritizing the retrofitting of existing buildings as a key strategy for reducing energy consumption in Nepal's building sector. Additionally, it highlights the need to update national building codes to mandate energy-efficient construction practices and to support local industries and startups in producing insulation materials from locally available, sustainable resources, supported by targeted policies and incentive programs to facilitate widespread adoption.

Keywords: Residential Building, Thermal Insulation, EnergyPlus, Passive design strategies, Energy Demand

## Revenue Potential of Mobile Substations Fitted with Battery Energy Storage in the Indian Electricity Market

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### Introduction

Energy transition and the concepts of decarbonization, decentralization, digitalization, and democratization are intertwined [1,2]. There are many competing candidates for energy transition and decarbonization. One of the candidates for energy transition and decarbonization are mobile substation fitted with a battery energy storage system. Flexibility in time and space is the hallmark of a mobile substation fitted with a battery energy storage system. Its flexibility in terms of deployment at any location to cater to various purposes provides resilience to distribution networks. Some of the occasions where electric distribution companies are likely to utilize it are: peak shaving during normal operation, addressing equipment malfunctions and managing essential loads during emergency conditions [3].

A mobile substation fitted with battery energy storage typically consists of modular energy storage units, power conversion systems (PCS), power control systems, and transformers, mounted on trailer-based or containerized platforms for rapid deployment [3,4].

Power supply reliability is of utmost concern in providing better service experiences to the users of electricity. So the task at hand for distribution companies is to provide electricity services with minimum interruption, even in the case of an emergency and serious fault in a substation. There may be instances when electricity distribution companies may struggle to restore the services due to various reasons. Overloading of transformers in summer can be tackled using a mobile substation fitted with battery energy storage systems. Whenever there is a major fault in the substation or there is a plan for substation expansion, a mobile substation can help in restoring the services to electricity users quickly. Another application of a mobile substation is in the case of preventive maintenance. Other factors, like increased power demand and industrial growth, can be met with mobile substations [5,6,7].

Many economies are witnessing the clean energy transition. As mobile battery energy storage systems do not contribute towards greenhouse gas emissions, they are an important tool in the clean energy transition. In this current phase of clean energy transition, a mobile substation equipped with a battery energy storage system is one of the alternatives capable of performing designated tasks. It is capable of providing ancillary services as well as energy arbitrage opportunities. This capability of participating in the energy market shows its revenue-generating capability during normal operation [8,9,10]. A trailer-mounted mobile battery energy storage fleet can be used for renewable curtailment and unmet loads during emergencies by charging at the location of excess energy and meeting location without power adequacy [11-12]. Flexibility, being the hallmark of Battery energy storage systems based mobile substations, it can switch from one purpose to another purpose readily [13]. Estimation of potential revenue from energy arbitrage for different storage technologies including Lithium-ion batteries for different times of charging and discharging was carried out

for the California market in the United States. Potential revenue from battery energy storage by making it portable by mounting it on a truck results in an increase in revenue substantially in California in terms of spatiotemporal arbitrage [14-15]. This paper finds the revenue potential of a mobile battery energy storage system using optimization techniques in GAMS coding for year 2023, 2024 and 2025 if it participates in the energy market in arbitrage service in the Indian Energy Exchange (IEX).

## Methodology / Approach

### Estimation of Revenue for Battery Energy Storage

The problem is formulated as a linear programming optimization model taking into account the operational constraints of the battery energy storage system. The inputs required for the optimization model are: hourly market prices and characteristics of battery energy storage systems. A linear programming optimization has been performed on historical data to determine the optimal quantities of electricity that should be purchased and sold subject to the constraints of the storage system and maximize the revenue. The optimization model with the objective function and constraints for optimized revenue calculation for arbitrage, day-ahead electricity price data from IEX exchange, and storage battery parameters are detailed below [16].

### Battery Storage Model for Arbitrage

State of Charge (SOC) of a storage battery at time  $t$  for energy arbitrage service is the function of SOC of the battery at a time prior to  $t$ , Power recharged for a  $\Delta t$  interval, and Power discharged for a  $\Delta t$  interval.

Mathematically, the SOC of a battery is stated as:

$$SOC(t) = (1 - d)SOC(t - \Delta t) + [\eta P_R(t) - P_D(t)]\Delta t \quad (1)$$

Where,  $d$  is the self-discharge of the battery, the term  $(1-d)$  is termed as storage efficiency also. The storage efficiency is a fraction of the stored energy maintained over one period.

$\eta$  is the round-trip efficiency or conversion efficiency of the storage battery (fraction of input power that gets stored),  $P_R(t)$  is the power recharged at time  $t$ ,  $P_D(t)$  is the power discharged at time  $t$ , and  $\Delta t$  is the time period between time  $t$  and a time prior to  $t$ .

### Optimization Model for Revenue from Energy Arbitrage

Linear Program for optimization consists of objective function and constraints. The objective Function of a Linear Program for the optimization of revenue from arbitrage is given by:

$$\text{Maximize } \sum_{t=1}^T [(E_{price}(t)(P_D(t)\Delta t)) - (E_{price}(t)P_R(t)\Delta t)] \quad (2)$$

$E_{price}(t)$  is the price of electricity at time  $t$ . The revenue from arbitrage is generated when electricity is sold in the energy market when the price of electricity is higher, i.e. storage battery gets discharged during this period, and electricity is purchased for recharging the storage battery when the electricity price is lower in the energy market. The first term in equation 2 is the product of the electricity price and the discharging energy of the battery, and the second term is the product of the electricity price and the recharging energy.

subject to the following constraints:

$$0 \leq SOC(t) \leq SOC_{max} \quad (3)$$

$$0 \leq P_D(t)\Delta t \leq P_{Dmax}\Delta t \quad (4)$$

$$0 \leq P_R(t)\Delta t \leq P_{Rmax}\Delta t \quad (5)$$

The decision variables ( $P_D(t)$ ,  $P_R(t)$ ) have been assumed to be non-negative numbers to fulfil non-negativity constraints.

where, SOC is the state of charge of the battery,  $P_D(t)$  is the discharging power of the storage battery at any time t,  $P_R(t)$  is the recharging power of the storage battery at any time t, and  $\Delta t$  is the time interval,  $SOC_{max}$  is the rated capacity of the storage battery, and  $P_{Dmax}$  and  $P_{Rmax}$  are the rated storage battery power for discharging and recharging.

### Electricity Price Data

The data for the calculation of arbitrage revenue was taken from IEX, India for the year 2023, 2024 and 2025 [17]. For revenue calculation, a linear program was solved using the simplex method-based CPLEX optimizer. Specifically, the GAMS software package was used to run the CPLEX optimizer.

### Battery Storage Parameters

A Li-ion battery has been selected for mobile substation based on ES-Select tool. The battery selected for mobile substation is 100 kW/150 kWh. In emergencies, this mobile substation mounted with battery energy storage systems will help in providing energy supply by discoms with minimum disruption, and during normal times it can participate in arbitrage services and ancillary services. The battery storage parameter for the chosen storage battery of 100kW/150 kWh has been shown in Table I.

**Table I.** Storage battery parameter for revenue analysis (Li-ion 100 kW/150 kWh) [18,19]

Parameter	Value
$P_{Dmax} \Delta t$ (Maximum discharging power for an hour i.e. maximum quantity that can be sold in a single period )	100 kWh
$P_{Rmax} \Delta t$ (Maximum recharging power for an hour i.e. maximum quantity that can be purchased in a single period)	100 MWh
$SOC_{max}$ (Maximum state of charge i.e maximum storage capacity of storage battery)	150 kWh
Efficiency (Roundtrip efficiency)	0.85
(1-d) i.e. storage efficiency	1

### Results / Findings

Monthly optimization of revenue for arbitrage in IEX for Li-ion battery of 100 kW/150 kWh has been done by Generalized Algebraic Modeling System (GAMS) coding. Decision variables in GAMS coding for estimating arbitrage potential (objective function given by equation 2, constraints represented by equations 3,4 and 5, and State of Charge given by equation 1) are:  $P_d(t)$ ,  $P_r(t)$ . The result of GAMS coding for linear program optimization has estimated energy arbitrage revenue potential for every month of the year 2023, 2024 and 2025 in the Indian Electricity Exchange (IEX) and has been shown in Fig. 1, Fig. 2 and Fig. 3. Average hourly prices for IEX India for 2023-2024 and 2024-2025 have been plotted in Fig. 4 and Fig. 5 respectively. The revenue for January, February and December is generally on higher side in each year. There may be various reasons for this including temperature difference, wind speed etc. An increase in variable renewable energy sources like wind and solar in certain months has resulted in higher trade volume for IEX.

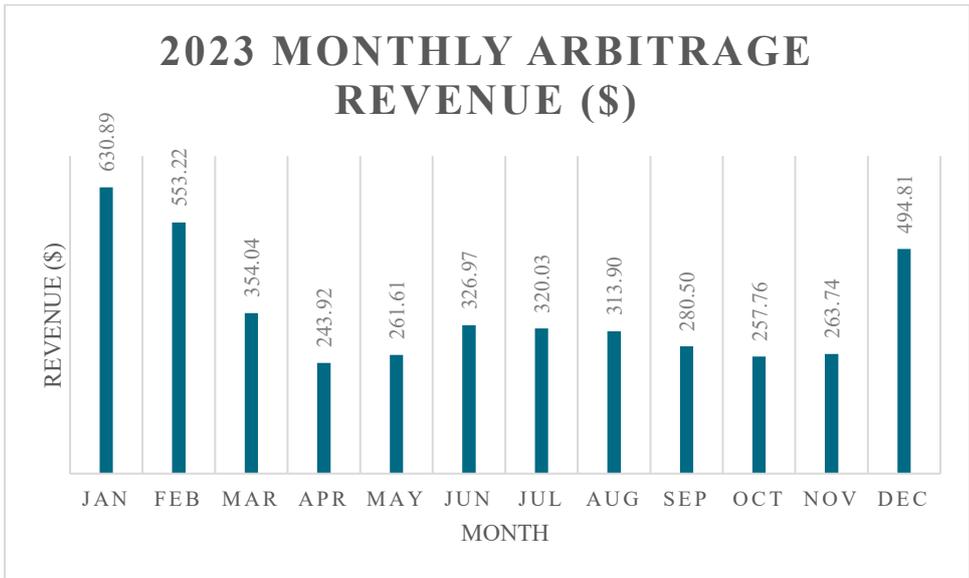


Fig.1: Summary of arbitrage optimization result, IEX India, 2023

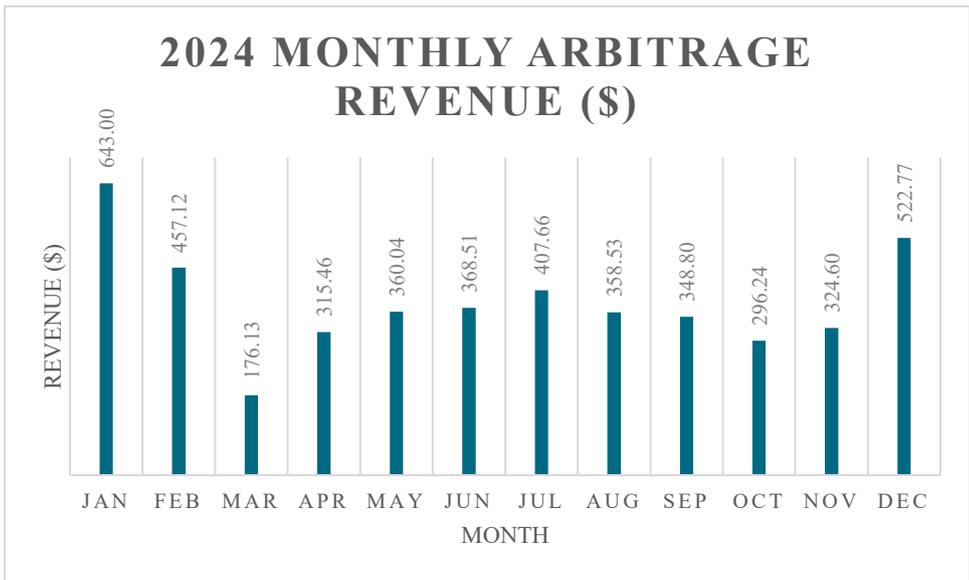


Fig.2: Summary of arbitrage optimization result, IEX India, 2024

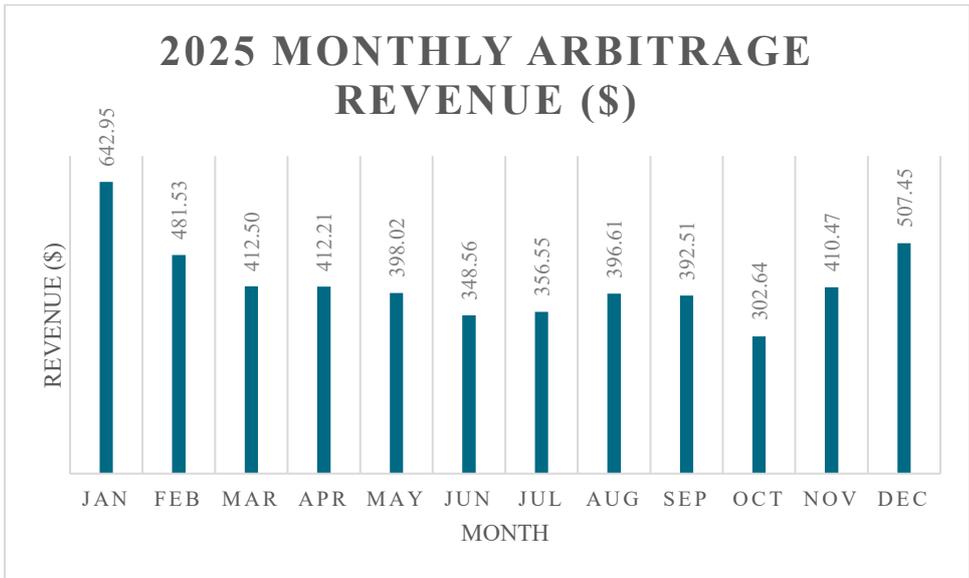


Fig.3: Summary of arbitrage optimization result, IEX India, 2025

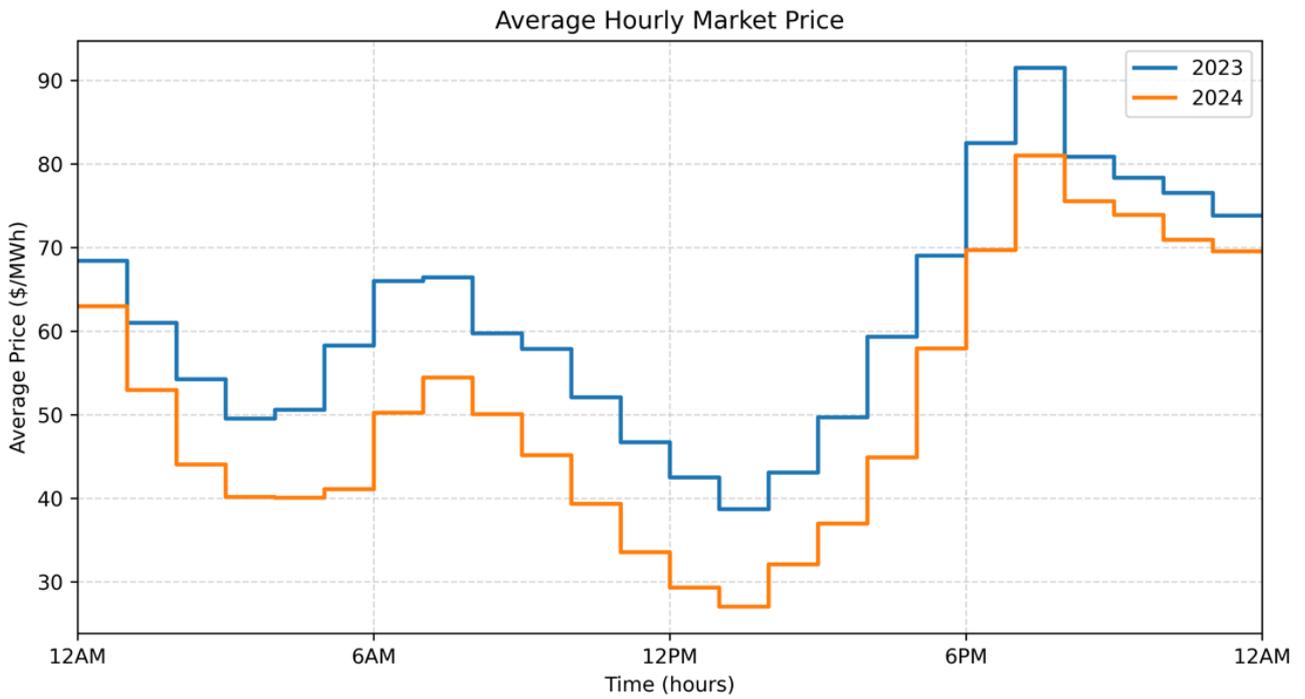


Fig.4: Average hourly prices for IEX India, 2023-2024 data

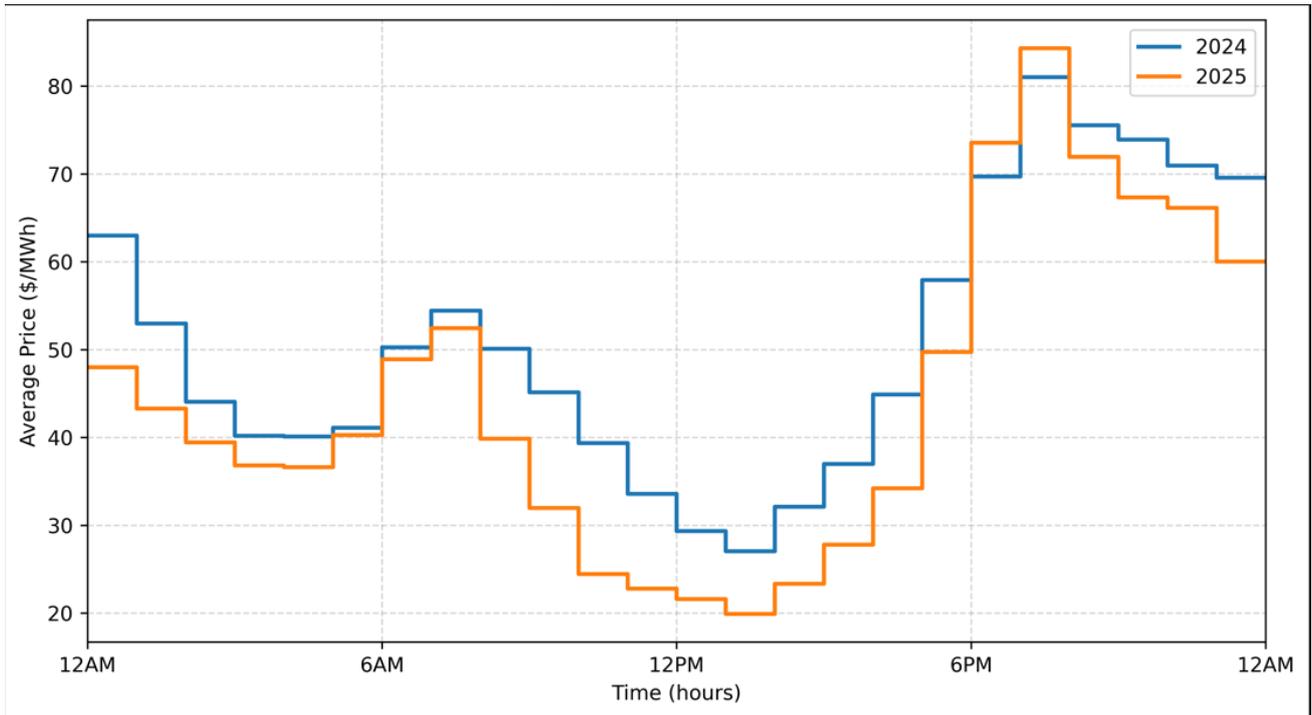


Fig.5: Average hourly prices for IEX India, 2024-2025 data

## Discussion / Conclusion

Mobile substation fitted with battery energy storage systems are capable of providing services during normal operation and emergency operations. During normal operation, mobile substation with battery energy storage can provide a host of services that include ancillary services and arbitrage services. This paper has estimated the potential revenue that can be generated by arbitrage services in the Indian Energy Exchange (IEX). Storage battery selected for this purpose based on ES-Select tool finds Li-ion battery suitable. Li-ion battery of 100 kW/150 kWh has been determined to be suitable for this purpose. The revenue for the year 2023, 2024 and 2025 in the IEX has been estimated by solving the constrained optimization problem using a linear programming approach. GAMS implementation of the CPLEX package was used to achieve the same. The estimated revenue for the year 2023, 2024 and 2025 for 100 kW/150 kWh Li-ion battery in the IEX comes out to be \$ 4,301, \$ 4579 and \$ 5062 respectively. Average yearly price for each time slot (24 time slots i.e. hourly) shows arbitrage opportunities.

*Keywords:* mobile substation, battery energy storage system, arbitrage revenue, energy transition

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## **Hybrid Heating Performance in Multi-Family Buildings Under Dynamic Energy Pricing**

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### **Abstract**

Hybrid heating systems that combine district heating, heat pumps, solar energy, and smart control technologies show strong potential to reduce both energy use and heating costs in multi-family buildings. By exploiting hourly price variations for electricity and district heating and optimizing system operation accordingly, heating demand can be shifted to more cost-effective periods. Results indicate that total energy use can be reduced by approximately 15–32 %, while district heating demand can decrease by up to 48 %. At the same time, peak loads can be significantly lowered, leading to substantial savings in district heating power tariffs.

The analysis shows that the most cost-effective strategy is to prioritize reducing district heating peak loads during the winter tariff measurement period, while electricity price control and load shifting are particularly effective during the summer months when district heating prices are lower. Combining heat pumps with solar PV and storage further enhances performance by enabling operation during low-price hours and reducing dependency on expensive energy periods.

Overall, the findings demonstrate that hybrid heating systems—when optimally controlled and adapted to local tariff structures—can deliver significant energy savings, economic benefits, and increased flexibility in building heating systems in an energy market characterized by growing price volatility.

## **Energy transition under the “Green Deal” – From the perspective of an industrial company**

Emma Tidstrand <sup>1\*</sup>

<sup>1</sup> Circular Economy NIBE

### **Abstract**

This presentation examines how European climate and energy policies, particularly the European Green Deal and the Fit for 55 initiative, are reshaping the industrial landscape within the EU energy system. These policies signal a deep transformation toward climate neutrality and they require companies to rethink how they design products, manage operations and plan long term strategies.

The EU is introducing a new regulatory framework aimed at building a circular, resource efficient and environmentally sustainable economy. Key initiatives such as the Ecodesign for Sustainable Products Regulation and emerging circular economy legislation establish clear expectations for product durability, reparability, energy performance, material recovery and digital product transparency (DPP). For the heat pump industry, this means moving toward more robust products, deeper lifecycle responsibility and significantly higher expectations on material traceability and recycled content.

These changes in legislation will fundamentally influence how companies operate. Product development will require closer integration of sustainability considerations from the earliest design stages. Supply chains will need greater transparency and collaboration to ensure responsible sourcing and improved traceability. Organisations will shift from traditional linear models toward circular systems where maintenance, reuse and recovery become integral parts of business strategy.

Using the heat pump industry as a case study, the presentation illustrates how new regulatory requirements covering durability, reparability, energy efficiency, recycled material content are driving manufacturers to fundamentally rethink product development, internal ways of working and organisational processes changes.

Overall, the presentation highlights both the opportunities created by the EU’s regulatory transformation and the practical challenges industrial companies must address to remain competitive while contributing effectively to Europe’s climate-neutral and resource-efficient future.

## **Beyond Checklists: Bundling Multi-Hazard Resilience in Climate-Smart Renovation for Buildings**

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Shashwat Sinha<sup>1</sup>  
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### **Introduction**

Buildings are increasingly exposed to compound and cascading climate hazards, yet most assessment practices still rely on single-hazard checklists that treat measures as independent. This creates blind spots: deep renovation and major construction decisions—typically made only once or twice in a building’s lifecycle—can lock in performance for decades, amplifying both co-benefits and unintended trade-offs. Motivated by the need for transparent, tool-ready guidance to support bundle-based retrofit strategies and Climate Smart Renovation (CSR), this study develops an interaction-aware framework to help practitioners prioritize measures that deliver multi-hazard benefits while avoiding cross-domain trade-offs.

Our aims are to: (i) consolidate a validated set of building-level resilience indicators spanning flood, fire, wind, thermal, and energy performance; (ii) map the synergies, trade-offs, and interdependencies among them using a Cross-Impact Matrix (CIM); (iii) analyse the interaction structure as a directed network to identify core, bridge, influencer, and isolate indicators; and (iv) translate these insights into prioritisation logic for retrofit bundling and composite resilience assessment.

### **Methodology / Approach**

We conducted a systematic literature review to identify building-level resilience indicators and consolidated 31 indicators across five domains: flood, fire, wind, thermal, and energy. This consolidation was refined through expert consultation to ensure practical relevance and comprehensive coverage across hazards.

These 31 indicators were then structured into a Cross-Impact Matrix (CIM). We carried out a rapid pairwise assessment to identify potential relationships, classifying each as one of the following:

- Synergy (mutual reinforcement or positive spillovers),
- Trade-off (one measure inhibits or undermines another),
- Interdependency (sequence/compatibility constraints without directional benefit/harm), or
- No relation.

Using the populated CIM, we performed a preliminary network analysis, evaluating each indicator’s out-degree (influence exerted on other indicators) and betweenness centrality (ability to bridge domains).

This enabled us to:

- Identify core indicators offering broad, multi-hazard benefits,

- Detect bridging indicators that integrate domains (e.g., connecting thermal/energy considerations with hazard protection),
- Reveal influential indicators with directional effects, including trade-offs, and
- Flag isolated indicators with localized, hazard-specific value.

## Results / Findings

The interaction structure is predominantly synergy-dominant, indicating that bundle-based interventions (rather than isolated measures) are both feasible and advantageous.

- Core backbone: Envelope and structure-related measures occupy central positions with high influence and strong co-benefits. These include roof assembly multi-hazard resistance, roof design (pitch/geometry), and plinth-level elevation. In the earlier analysis, exterior door resistance also emerged as central in certain hazard combinations. Core indicators provide broad, cross-domain resilience and anchor effective bundles.
- Bridges / gateways: Elements such as wall assemblies and insulation function as cross-domain connectors, linking flood, fire, wind, thermal, and energy considerations. Their bridging role helps maintain coherence across the system, ensuring that multi-hazard retrofits behave as an integrated package rather than a set of disconnected upgrades.
- Influencers with potential trade-offs: Energy-use-related measures (e.g., heating/cooling demand and certain efficiency upgrades) can drive system-wide effects but may introduce trade-offs (e.g., interactions with ventilation, moisture, or fire performance) that require careful sequencing and detailing.
- Isolates: Measures such as backup power autonomy and stormwater-sewer separation tend to be hazard-specific with limited systemic influence, yet they remain critical for targeted risk reduction.

Collectively, the network— while acknowledging its preliminary status—reveals where co-benefits cluster, where attention to compatibility is essential, and how to sequence interventions to minimize unintended consequences.

## Discussion / Conclusion

This study contributes:

1. A validated, multi-hazard indicator set for building-level resilience.
2. An explicit interaction map that distinguishes synergies, trade-offs, interdependencies, and no relations.
3. A prioritization logic—derived from network position (core, bridge, influencer, isolate)— to support the design of retrofit bundles that maximize co-benefits and mitigate conflicts.

For practice, the framework is directly applicable to Climate Smart Renovation (CSR): every energy or comfort upgrade becomes an opportunity to embed hazard resilience, and vice versa. By bundling core and bridge indicators and managing influencer trade-offs, practitioners can develop transparent, auditable retrofit roadmaps that are tool-ready for composite resilience assessment. For policy and finance, the approach is setting the pathway to disclosure, prioritization, and funding mechanisms that reward multi-hazard, whole-building performance rather than siloed compliance.

Future work should calibrate indicator weights to context (building typologies, climates, regulatory regimes), test bundles empirically in real projects, and extend the interaction map to additional hazards and system layers (e.g., district-scale infrastructure couplings). Overall, this interaction-aware method shifts resilience planning from checklists to systems thinking, enabling smarter, timing-sensitive decisions that avoid lock-ins and deliver durable risk reduction.

**Keywords:** resilience, building-retrofit, climate-smart, indicators, multi-hazard



## **How can flood protection, nature conservation, and local recreation be combined in urban areas? Lessons from a case study in the German Lower Rhine area**

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### **Introduction**

Climate change will lead to more extreme events such as pluvial and fluvial flooding in urban areas in the coming decades. Cities need to prepare for this by creating more areas that can absorb and retain water. The restoration of rivers, streams and floodplains, as well as their protection as nature reserves, can be valuable instruments in this regard. Natural or restored floodplains are able to store (and filter) water and thus help to reduce runoff peaks. This makes them important nature-based elements in comprehensive sponge city designs. In addition, such areas can create valuable recreational spaces and access to nature for the local population, which are particularly valuable in densely populated urban regions.

Local authorities and regional administrations can promote projects for restoration and rehabilitation projects, but without the support of the local population and a wide variety of stakeholders, such projects may not be successful. Against this background, my contribution focuses on an outstanding example of a restoration of an extended floodplain between Cologne and Düsseldorf, two major cities in Germany. In particular, this study examines how the measures were implemented, how the local population assesses them, and what conflicts of use have arisen over time.

### **Methodology / Approach**

This paper follows a case study design. In 2014, the summer dike on the Old Rhine south of Düsseldorf was opened in two places, allowing the flow of water into the (former) floodplain. So-called (ecological) process protection in this area is intended to ensure self-sustaining ecological development and create a (new) wilderness on the outskirts of the city. This approach ensures that the watercourse can develop organically with minimal human intervention.

The Urdenbach Altrhein (Old Rhine) is a small stream, only about eight kilometers long. It is part of the Urdenbach Kämpe, one of the largest floodplain areas in the German Lower Rhine region that remains largely undeveloped to this day. Despite the dense development in the surrounding area, (extensive) agricultural use and small areas of riparian forest still dominate the Kämpe itself. The Kämpe was formed in the late 14th century when the Rhine shifted westward after a major flood event in 1374. Today, the Old Rhine runs through the old riverbed of the Rhine. Its stream bed was largely straightened and given a box-shaped profile in the 1950s. A summer dike was built southwest of the stream, which severely restricted the water dynamics for more than half a century and was intended in particular to prevent the adjacent meadows and fields from being flooded after heavy rainfall. This summer dike was opened, allowing the Old Rhine to find its own course again over a length of 2.5 km and restoring the natural flooding dynamics in the floodplain. Wooden bridges have been built over the two dyke openings so that the path on the summer dike can still be used by pedestrians and cyclists. The built-up area of Düsseldorf extends right up to the

northern edge of the site, making it an easily accessible local recreation area for around 70,000 people on foot or by bicycle. This increases the pressure on the nature reserve and leads to competing demands in some cases (e.g., enjoying nature, enjoying peace and quiet, cycling, walking dogs).

The seasonally changing water bodies have increased significantly after 2014, and the natural reintroductions of beavers and storks are notable successes for nature and species conservation. However, restoration also leads to restrictions on use and changes to the familiar landscape, for example due to the death of the hybrid poplars that previously dominated the landscape.

The opening of the dyke at the Old Rhine has been accompanied by extensive surveys of visitors conducted by the Geography Department of the University of Cologne from 2015 to the present. During the summer months of 2015, 2018, and 2024, a total of over 1,300 people were surveyed, primarily about their reasons for visiting, their assessments of the development of the area, and possible conflicts between different user groups. Although the individual surveys focused on different topics, they also contained questions that were identical in the different years, thus enabling a comparison over the nine-year period. The representativeness of the data was ensured by conducting parallel counts of visitors to the area, randomly selecting the people surveyed, and performing statistical bias tests.

## **Results / Findings**

Our analyses show that the Old Rhine restoration area is heavily frequented, with its visitor catchment area expanding steadily in recent years. Our estimates for 2024 assume that an average of 400 to 500 people entered the area between the two dike openings every day during the summer months from May to September. Around 15 % of the people counted in 2024 had dogs with them. The high number of visitors can be seen as a success for the restoration measures, but it also places a considerable strain on the ecosystem.

Before the restoration measures were implemented, there were considerable concerns among the local population regarding the potentially negative effects on flood protection, which were caused in particular by the announcement of the double dyke opening. A major reason for this was the misconception that the dyke had been built to protect urban settlements. In fact, however, it was only built to protect farmers' crops from flooding caused by heavy rainfall in the summer. It never had any significant function in protecting urban development. Thanks to sensitive information campaigns and the positive experiences following restoration, these initial fears quickly subsided. Today, the vast majority of people see flood protection as a (positive) key feature of the restoration project. When asked how important flood protection in the Urdenbach Kämpe is to them, 39 % answered "very important" and 41% answered "important." These percentages have remained relatively stable over the years, although they have declined slightly, presumably due to the predominantly positive experiences with flooding after 2014.

Visitors rate the recreational and leisure value of the Old Rhine area extremely positively. This also applies to the different restoration measures that have been carried out. The vast majority of respondents also welcomes the fact that humans no longer interfere with the course of nature. A clear majority of people also states that the area corresponds to their idea of "wilderness." The death of trees due to increased waterlogging is only a concern for a minority, even though this proportion has risen slightly in recent years due to the large number of dead trees that become more and more visible.

Despite the high approval ratings for process protection, a large majority of respondents rejected the idea of completely restricting access to the Old Rhine area. Only very few of those surveyed would consider such

far-reaching protection measures to be an option. “Wild nature” is welcome, but it must be reasonably accessible. However, restrictions imposed by nature conservation, such as a ban on leaving the footpaths or the requirement to keep dogs on a leash, are overwhelmingly supported.

Given the high number of visitors to the Old Rhine area, it is hardly surprising that some visitors find each other disruptive. It is noteworthy that this applied to around half of all respondents in 2024, which is double the proportion compared to 2015. This increase in the perceived potential for conflict affects almost all reasons for possible disturbances (e.g., noise, litter, vandalism, photographers standing in the way), but cycling in particular. The fact that the potential for conflict involving dogs has increased less significantly in comparison may be due to the increasing number of dogs being kept on a leash. The rather gentle methods used by the responsible Biological Station – friendly signs, special tours for dog owners, and in many cases personal contact – were apparently successful, even though too many dogs are still not kept on a leash.

The increasing sense of conflict may be a sign of the overall social development of recent years, which is also noticeable in a nature reserve, but the increasing conflicts surrounding cycling might also have more specific reasons. Not only has the number of cyclists increased overall, but there are also more people on “pedelecs”, i.e., motorized bikes that often travel at higher speeds. However, the increasing conflicts are only one side of social interactions. Our results also highlight the important social and communicative function of nature conservation areas.

## **Discussion / Conclusion**

The example of the Old Rhine restoration area shows that the creation of retention areas along rivers and nature conservation can go hand in hand. If the measures are planned and implemented in a participatory manner and enable the involvement of various stakeholders, it is possible to win over the local public even for rather ambitious changes. Our surveys indicate that the renaturation of the Old Rhine was not only successful from an ecological and a flood protection point of view, but also strengthened the area's recreational function. Visitors overwhelmingly rate both the restoration and the idea of process protection rather positively – despite the restrictions imposed by nature conservation. Inherent contradictions also exist within the framework of ecological process protection between the goal of “letting nature be nature” and yet, for example in the case of the spread of neophytes, repeated human interventions in the sense of ideal notions of “true nature”.

The area around the Old Rhine still is subject to repeated (moderate) intervention, for example when the spreading giant hogweed is removed or the equally neophytic ash-maple is ringed. These contradictions are also evident among visitors to the area. On the one hand, the spread of non-native species is seen as a natural process, restrictions under nature conservation law are largely accepted, process protection approaches are welcomed, and the area around the Old Rhine is perceived as “wilderness.” On the other hand, many people nevertheless advocate targeted interventions, and further restrictions on accessibility are overwhelmingly rejected.

Despite the many positive aspects of floodplain restorations, their actual effects on flood protection have not yet been thoroughly investigated empirically for larger catchment areas. Further research will be necessary in the future.

*Keywords:* river restoration, floodplains, nature conservation, flooding, retention areas, Lower Rhine region

## The Weight of Adaptation: Determining the Causal Role of Climate-Proofing in Swedish Property Valuation

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### Introduction

Residential real estate is the largest asset class in modern economies, functioning as a multidimensional bundle of structural and environmental attributes (Case et al., 2005). Under hedonic theory, prices reflect the "shadow prices" of these specific components rather than a single uniform product (Rosen, 1974; Sirmans et al., 2005). In Sweden, climate impacts have evolved from future threats into material economic realities. Extreme precipitation and flooding are physically degrading the foundations and building envelopes of older housing stock (Füssel, 2018; Insurance in Sweden, 2025a). Consequently, water-related damages are now the fastest-growing category of residential insurance payouts. The financial stakes are staggering. Approximately 8% of Swedish homes—valued at SEK 160 billion—sit less than five meters above sea level, representing 5% of the nation's total mortgage collateral (Danielsson, 2020). This risk is violently unequal: Southern Sweden and Skåne are primary catastrophe zones due to low elevation, while northern regions benefit from natural land uplift (Danielsson, 2020). Across all Nordic countries, flooding risk is now recognized as a primary determinant of property liquidity and long-term asset value (Sandin, 2025).

To counter these threats, climate-adaptive renovations like flood-proofing and drainage upgrades have emerged as vital survival strategies (Sandin, 2025). However, their market value remains an "ambiguous black hole." Because benefits are probabilistic and long-term, they are often invisible at the point of sale, creating severe information asymmetries (Akerlof, 1970; Pryce, 2011). Furthermore, short-term market sentiment frequently drowns out long-term risk signals (Hu & Lee, 2020). Quantifying a "resilience premium" is therefore essential to determine if the market effectively rewards climate-ready homes or remains blind to escalating structural risks.

### Methodology / Approach

This study quantifies the "resilience premium" in the Swedish single-family housing (SFH) market using a multi-stage pipeline. A Python pipeline scraped Fastighetsbyrån to generate a primary dataset, integrating network distances to amenities via the OpenStreetMap API to account for spatial accessibility. To resolve the lack of standardization in listings, an OpenAI Large Language Model (LLM) was employed to classify renovations—specifically isolating climate-adaptive measures like flood resistance, moisture protection, and roof reinforcement from aesthetic or energy-efficient upgrades. This semi-supervised, iterative process achieved 94% accuracy across 2,453 listings. To determine the weightage of individual attributes, the XGBoost (Extreme Gradient Boosting) algorithm was selected for its superior ability to capture non-linear interactions without the strict assumptions of homoscedasticity in comparison to traditional OLS models (Mora-Garcia et al., 2022). The model utilizes log-transformed prices and was optimized via a 500-iteration randomized search, targeting parameters such as learning rate, tree depth, and regularisation (Jaroszewicz & Horynek, 2024). A 3-fold cross-validation strategy ensured hyperparameters remain robust across geographical partitions, addressing the spatial dependencies inherent in real estate markets (Osland & Thorsen, 2013). Final attribute weightages were

extracted using SHAP (Shapley Additive Explanations) and Gain-based metrics to empirically observe whether climate-adaptive renovations have emerged as a significant value driver.

## **Results / Findings**

The empirical results of this study reveal a significant distinction between the two utilized XGBoost modeling approaches: the levels-based model, using raw price per square meter, and the log-transformed specification. The levels-based model yielded a moderate in-sample training fit with an  $R^2$  of 0.66; however, it demonstrated exceptionally poor out-of-sample predictive quality, with a test  $R^2$  of only 0.39 and a Mean Absolute Percentage Error (MAPE) exceeding 60%. This substantial prediction error suggests that the levels-based approach fails to generalize effectively, primarily due to its inability to manage outliers and the sharp increase in variance at the upper end of the price distribution. Conversely, the log-transformed model exhibited significantly enhanced performance stability and predictive accuracy. While the test  $R^2$  improved slightly to approximately 0.42, the most dramatic finding was the reduction in test MAPE to 6.3%. This represents a critical improvement in relative prediction error. The closer alignment between training and testing metrics in this specification indicates that the log transformation successfully mitigates the effects of heteroscedasticity, effectively stabilizing the uneven variance caused by extreme price values. These results, which align with established real estate econometric literature, necessitated the exclusive use of the log-transformed model for subsequent feature importance analysis.

The global feature importance rankings, derived from SHAP values and Gain-based metrics as illustrated in Figures 1 and 2, show remarkable consistency between the two model specifications. The upper tiers are dominated by fundamental structural attributes: the total number of rooms, floors, bedrooms, living area, and the year of construction. This dominance establishes a clear foundation for market valuation, where these core features dictate the base price of a dwelling. Other property attributes, including renovation status, then serve as modifiers that adjust this base value according to the specific characteristics of the asset. The near-identical relative rankings of these features across both model types provide high confidence in the robustness of the identified relationships. This stability indicates that the XGBoost architecture has successfully captured a consistent value-formation mechanism within the Swedish single-family housing market. While absolute SHAP magnitudes differ, the consistent prioritization of structural determinants suggests the model is identifying economically rational pricing signals rather than random correlations. This robust framework allows for a reliable interpretation of how secondary attributes, such as climate-adaptive renovations, influence final market valuations.

## **Discussion / Conclusion**

The study concluded that morphological and structural characteristics of dwellings (size, design, and when it was built) were the biggest factors in the pricing of homes in the Swedish single-family housing market. The amount paid per square meter for homes with climate-adaptive renovations has a moderate positive effect but is still significantly lower than the other criteria for valuing properties, leading researchers to conclude that while homeowners have begun to recognize climate-adaptive renovations through price appreciation, the effect of climate-adaptive renovations continues to be a limited effect in the marketplace.

The findings of this study are significant for several reasons. For homeowners, climate-adaptive renovations have the potential to add value to their home in areas of high risk; however, they may not yield a large price premium. For those who appraise homes and engage in the housing market, this study illustrates the difficulties associated with pricing properties when the risk is not adequately accounted for in the pricing. For those involved in developing policy, the limited response of the market to climate-adaptive renovations supports the need for the development of targeted incentives, regulations, and information disclosure to encourage homeowners to perform climate-resilient retrofitting.

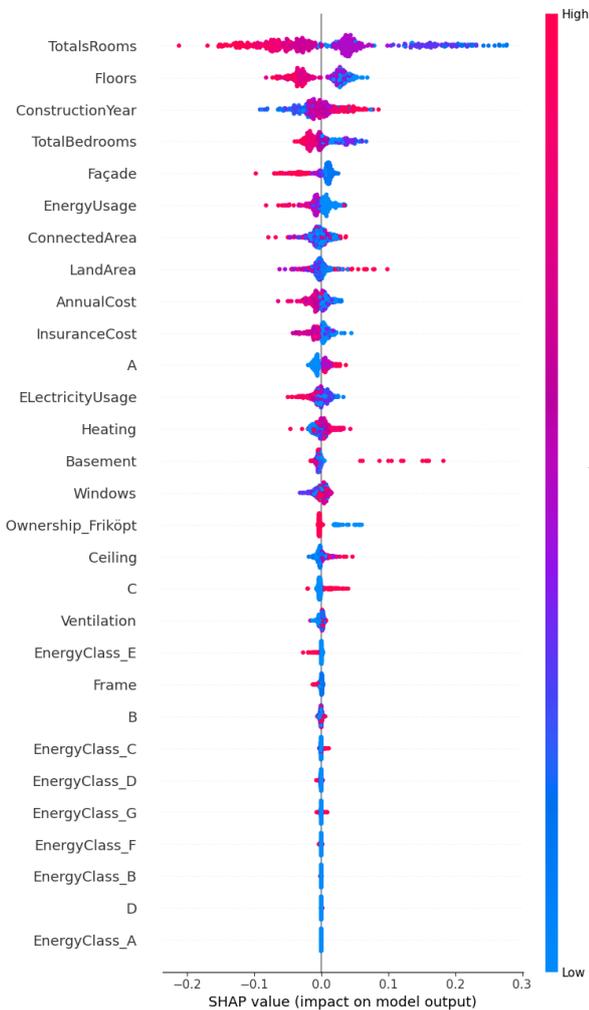


Figure 1 SHAP values for different housing attributes

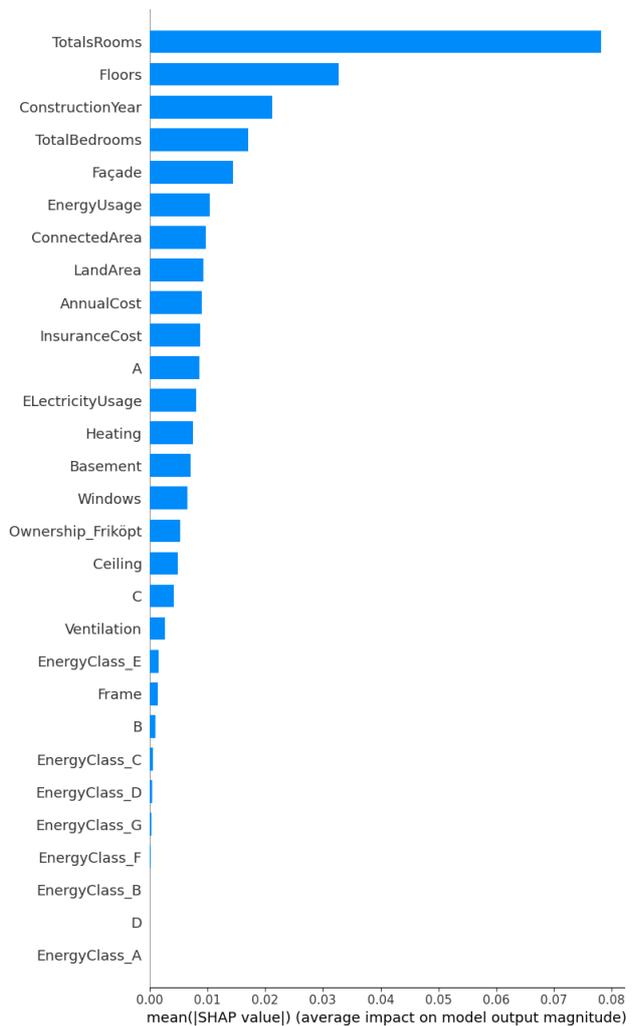


Figure 2 Mean SHAP values for different housing attributes

The limitations discussed above should be noted. The analysis has been limited to transaction data and does not discuss cause/effect relationships; also, climate risk was used as an indirect measure via renovations features and does not look directly at hazard exposure or actual physical damage. Future work should explore new modelling options to identify conditions that will cause more homeowners to perform climate-smart renovations and to quantify how much value these climate-smart renovations add to a home. Tools such as spatial econometrics, causal inference techniques, and longitudinal or repeat-sales designs, in combination with machine-learning methodologies would produce context-specific estimates regarding the evolution of resilience premiums in different geographic areas, across different market conditions, and in the aftermath of various types of climate-related disasters.

**Keywords:** Urban climate risk, climate-smart retrofitting, real estate evaluation, machine learning, large language models

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## Potential mitigation of urban heat island effect through azolla cultivation modules integrated on rooftops: A thermodynamic modelling study

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### Introduction

Climate change and rapid urbanisation are intensifying thermal stress in urban built environments, with heatwaves increasingly driving peak cooling demand, energy insecurity, and public health risks. Urban heat island (UHI) effects are amplified dominantly by impervious surfaces, reduced evapotranspiration, and the widespread rejection of anthropogenic waste heat from air-conditioning systems, among other factors. While albedo-based interventions such as cool roofs and green roofs are widely promoted as climate mitigation measures, their performance is often climate-dependent and primarily focuses on reducing solar heat gains, with limited consideration of thermal inertia and downstream waste heat source suppression.

There is an immediate need for climate-resilient, cost-effective, and decentralised adaptation strategies that can be retrofitted onto existing buildings, particularly in rapidly urbanising regions of the Global South. This study investigates the potential use of azolla, a rapidly growing aquatic fern on urban rooftops to mitigate UHI effects. The following sections detail azolla-based rooftop aquatic systems as a nature-based intervention that integrates passive thermal buffering, evaporative cooling, and shading, while simultaneously reducing cooling energy demand, HVAC waste heat emissions, besides active photosynthetic carbon capture and second-order effects of avoided GHG emissions. The study aims to quantify these impacts through a transparent, first-principles thermodynamic framework and to assess their relevance for UHI mitigation.

### Methodology

A thermodynamic mathematical model was developed to compare the heat transfer performance of a conventional exposed roof with that of a roof retrofitted with a shallow azolla-covered water layer. New Delhi was selected as the case study due to its extreme summer temperatures, strong urban heat island intensity, and rapidly increasing cooling energy demand, which together represent a high-stress urban thermal environment. The city's dense built form, widespread flat rooftops, and availability of reliable .epw (EnergyPlus weather files) climate data make it a suitable and conservative test case for evaluating rooftop-based heat mitigation strategies. Hourly climatic boundary conditions were obtained from .epw files and processed using Climate Consultant, including dry-bulb air temperature, global horizontal irradiance, wind speed, and relative humidity.

The rooftop aquatic system was modelled as a shallow water body covered by azolla and shaded by a 50% transmissivity net. The transient energy balance of the water layer was expressed as:

$$\rho_w c_{p,w} h \frac{dT_w}{dt} = \alpha S - h_c(T_w - T_a) - L_v E - \varepsilon \sigma (T_w^4 - T_{sky}^4)$$

The LHS term represents the lumped thermal capacity of the azolla cultivation medium and the RHS terms represent absorbed solar radiation after albedo effects of façade material, convective heat exchange, evaporative heat loss, and longwave radiative exchange, respectively. Heat transfer into the building was calculated using a one-dimensional conductive model based on temperature gradient and thermal resistance of a template roof facade:

$$Q_{roof} = \frac{T_{ext} - T_{in}}{R_{roof}}$$

Cooling energy demand was calculated by assumption of a coefficient of performance in tandem with industry averages, and avoided anthropogenic waste heat was estimated from the reduction in condenser heat rejection. Avoided emissions from offset cooling energy demand was calculated by assigning a grid emission factor for the national grid (0.716 kgCO<sub>2e</sub>/kWh<sub>e</sub>) and a reference coefficient of performance (3.5) for Indian HVAC appliances. Hourly simulations were performed for an entire year, and results were reported on a unit roof area basis, for future studies on scalability and composite impacts of large-scale deployment of such intervention measures.

## Results

The azolla-based rooftop system exhibited substantial attenuation of heat transfer into the building envelope, along with a temporal lag in maxima attainment, particularly during peak summer periods. On a unit area basis, maximum reductions in downward conductive heat flux of approximately 108.34 Wm<sup>-2</sup> were observed during peak hours. This resulted in annual avoided cooling energy of 16.6 kWh<sub>e</sub> m<sup>-2</sup>yr<sup>-1</sup>, with corresponding avoided anthropogenic waste heat of 74.8 kWh<sub>t</sub> m<sup>-2</sup> yr<sup>-1</sup>. The maximum hourly peak electrical cooling load reduction is found to be 30.9 W<sub>e</sub>m<sup>-2</sup>, indicating potential benefits for energy resilience during extreme heat events. The thermal inertia of the water layer produced a phase shift in heat transfer, reducing peak fluxes even under high ambient temperatures.

Furthermore, the biomass growth accounts for compounded direct atmospheric carbon dioxide drawdown of the order of 7.7 kgCO<sub>2</sub>m<sup>-2</sup>yr<sup>-1</sup>, while the emissions reductions effected by reduction in cooling energy demand is of the order of 11.9 kgCO<sub>2</sub>m<sup>-2</sup>yr<sup>-1</sup>, thereby leading to a net reduction and offset in atmospheric CO<sub>2</sub> of the order of 19.6 kgCO<sub>2</sub>m<sup>-2</sup>yr<sup>-1</sup>.

Avoided waste heat fluxes were translated into an equivalent UHI mitigation signal using a first-order urban canopy heat balance. Considering a conservative value of 20 meters for the urban canopy layer (h<sub>UCL</sub>), the governing equation is as follows:

$$\Delta T_{UHI} \approx \frac{Q_{avoided}}{\rho_{air} c_{p,air} h_{UCL}}$$

The above approach yields a conservative local UHI mitigation signal in the range of **0.01–0.5 °C**, contingent on rooftop coverage fraction and urban morphology. These magnitudes are consistent with reported impacts of established cool and green roof strategies, despite excluding mesoscale atmospheric feedbacks.

Table 1: Summary metrics for unit area implementation of rooftop retrofit through azolla cultivation

Metric	Value (per m <sup>2</sup> )	Units
Peak heat flux reduction	108.34	W <sub>t</sub> /m <sup>2</sup>
Annual cooling energy avoided	16.62	kWh <sub>e</sub> /m <sup>2</sup> yr
Annual waste heat avoided	74.82	kWh <sub>t</sub> /m <sup>2</sup> yr
Maximum peak cooling load reduction	30.9	W <sub>e</sub> /m <sup>2</sup>
Local UHI mitigation signal	0.01–0.5	°C
Carbon Dioxide Removed and Offset	19.6	kgCO <sub>2</sub> m <sup>-2</sup> yr <sup>-1</sup>

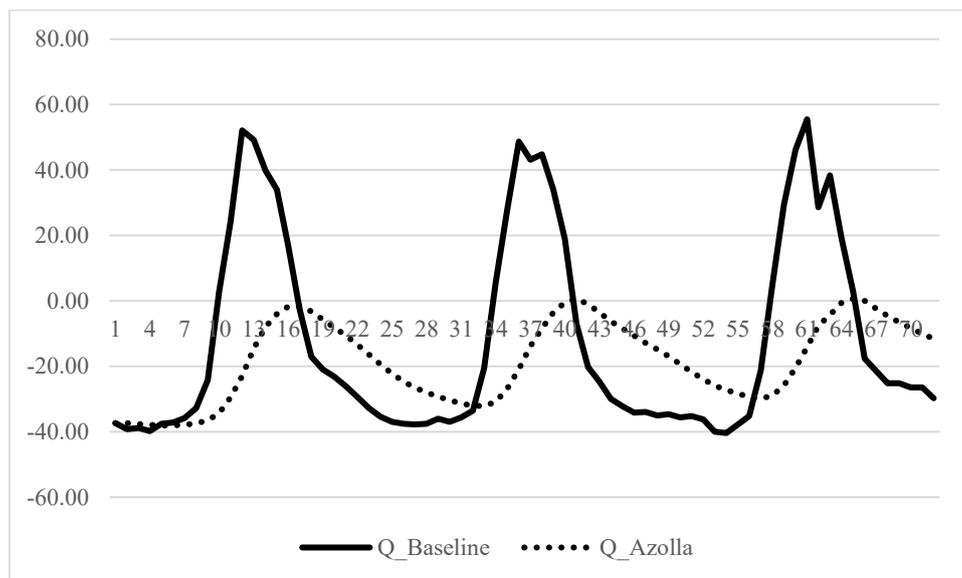


Figure 1: Downward conductive flux (Wm<sup>-2</sup>) for baseline roof and azolla integrated roof for 72 hours, exhibiting attenuation and lag characteristics

## Discussion

The results indicate that azolla-based rooftop aquatic systems operate through thermodynamic mechanisms distinct from conventional cool or green roofs. By combining high thermal capacity, sustained evaporative cooling, and upstream suppression of cooling-related waste heat, the system addresses both building-level thermal loads and urban-scale heat accumulation.

The decentralised and modular nature of the intervention aligns with grassroots and community-driven adaptation pathways, while its passive operation enhances resilience under conditions of grid stress or power outages. Although the analysis employs a simplified urban canopy model and does not account for mesoscale

atmospheric feedbacks, the results provide a conservative lower-bound estimate of UHI mitigation potential rooted in fundamental heat transfer principles. The approach offers a promising cost-effective pathway for climate-smart retrofitting of existing urban buildings, especially in the Global South.

## **Nature-Inclusive Residential Design: Industry Perspectives and Modular Innovation**

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### **Abstract**

The urgent need for sustainable housing requires design solutions that balance ecological preservation with construction feasibility. While research increasingly promotes nature-inclusive architecture—integrating biodiversity, soil health, and renewable systems—practical constraints often hinder large-scale adoption. This article combines insights from two complementary studies: (1) interviews with Swedish construction firms exploring challenges and opportunities for preserving natural habitats in residential development, and (2) an architectural design framework proposing modular timber-based elevated housing systems to safeguard ecosystems, manage water and energy, and enable localized food production. By integrating empirical industry perspectives with conceptual innovation, the article identifies barriers (cost, regulations, technical uncertainties) and opportunities (prefabrication, modular flexibility, elevated foundations) for mainstreaming nature-inclusive residential design. The findings highlight that reconciling ecological ambitions with construction realities requires adaptive regulatory frameworks, economic incentives, and demonstration projects. The conclusion argues that hybrid approaches—grounded in industry feasibility yet inspired by regenerative ecological design—are essential for future-proof housing.

*Keywords:* Nature-inclusive design; low-density housing; prefabrication; modular architecture; biodiversity; ecosystem services; Sweden

## Combustion optimisation on forward moving reciprocating grates

Damir Zibrat  
TECHNIKGRUPPE AUSTRIA

### Introduction

In this presentation theoretical backgrounds and practical applications of unique combustion optimisation method will be explained.

Combustion process in considerable number of biomass to energy plants and waste to energy plants is based on forward moving reciprocating grates.

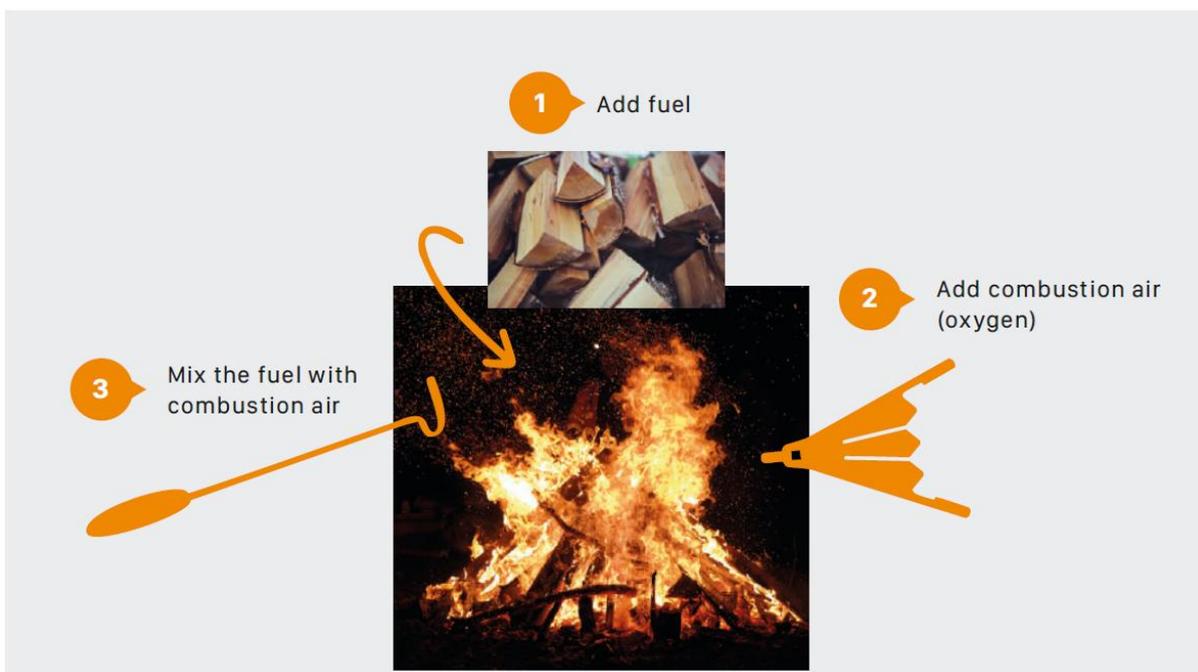
Main benefits of those grates are:

- Those grates are suitable for incineration of different fuels
- With appropriate methods those grates provide good base for control of incineration

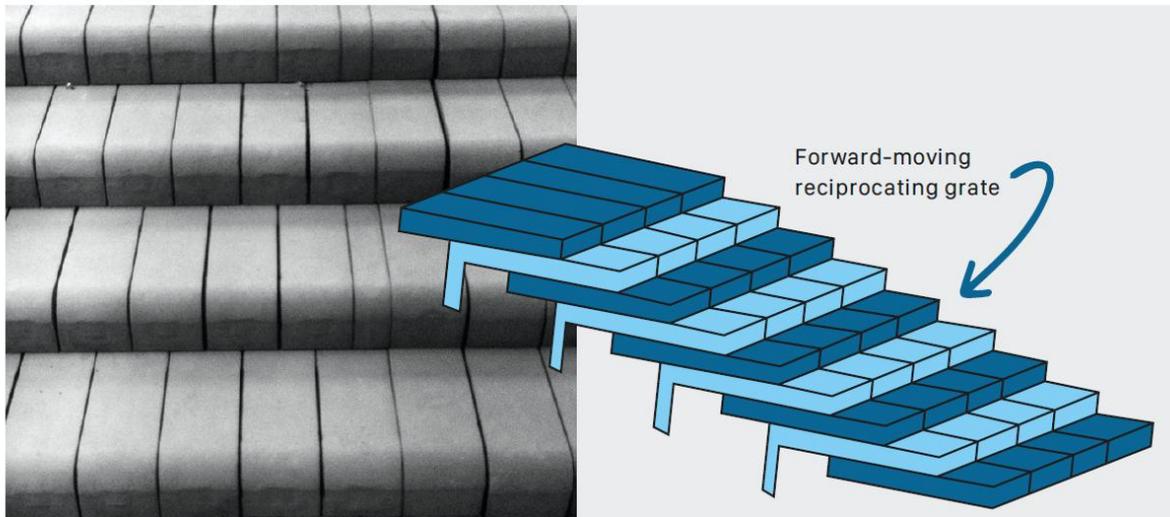
Combustion optimisation system (WiC) , described in this presentation, is placed in separate cabinet. System is "by pass" - do not replace old system – and can be implemented as **temporary testing system**.

### BASIC PRINCIPLE OF COMBUSTION CONTROL

**The control of the combustion process is based on 3 main actions:**



The technical process of combustion described above is best implemented using a forward moving reciprocating grate. On such a grate, the required amount of fuel in the various grate zones can be optimally and very precisely regulated by the WiC Combustion Manager.



**Control of combustion parameters is provided by ACTUATORS**



IF system has 20 actuators, and each actuator has 10 possible positions (combinations), number of allowed combinations is huge !

1	actuator provides	10 combinations	// 0-1-2-3-4-5-6-7-8-9-
2	actuators provide	100 combinations	// 00-01-02-03-04- .....96-97-98-99
3	actuators provide	1000 combinations	// 000-001-002-003-004-005-006-007 .....997-998-999
20	actuators provide	100 000 000 000 000 000 000 000 possible combinations	for fine adjustment.

Combustion status is changing every few seconds. That means that every few seconds is necessary to define appropriate combination of actuators ( one of BILIONS). This can be possible by implementation of:

- a) Existing process measurements ( typical about 100)
- b) Appropriate (complex) software
- c) Appropriate (strong ) hardware

Combustion control system described in this presentation has 6500 functional diagrams (instead usual 50 )

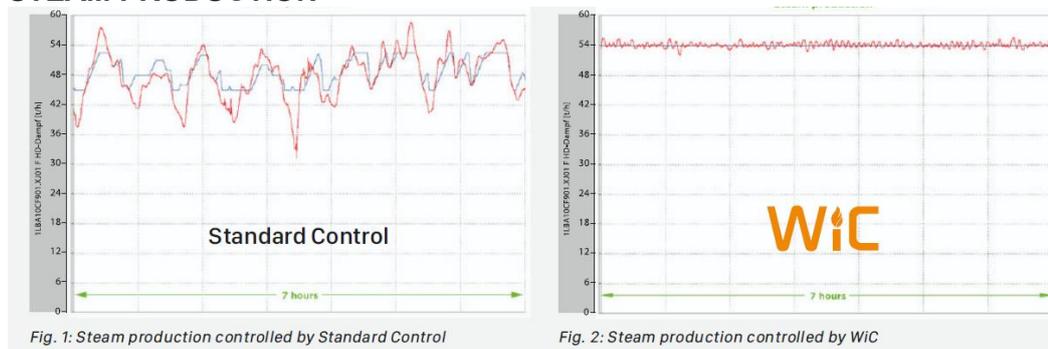


Combustion control system described in this presentation has hardware which simultaneously read 100 measurements and provide 20 – 30 output signals.



Below are some **practical results** of implementation of appropriate combustion control.

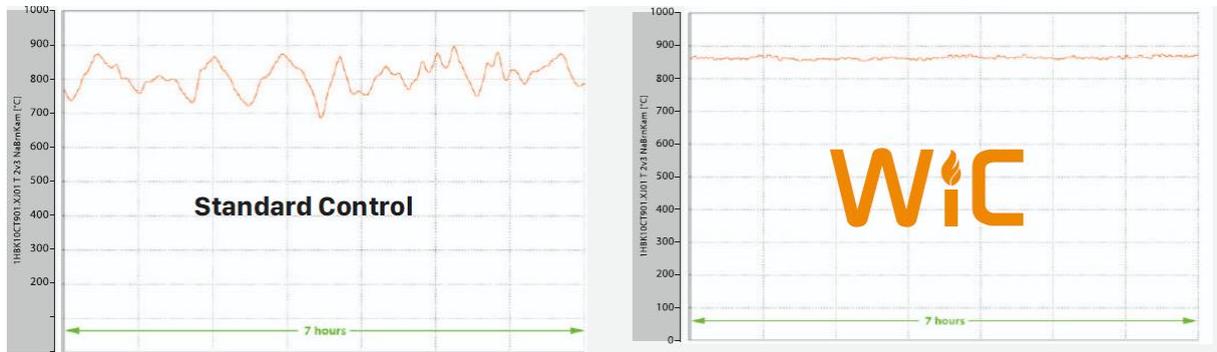
### STEAM PRODUCTION



### COMBUSTION AIR



## CEILING TEMPERATURE



### Methodology / Approach

Methodology used in this applications are based on control of adding of solid fuel in burning chamber control of movement of grate and air supply

### Results / Findings

On diagram below are described results of increase of combustion capacity for 10% Without mechanical changings.

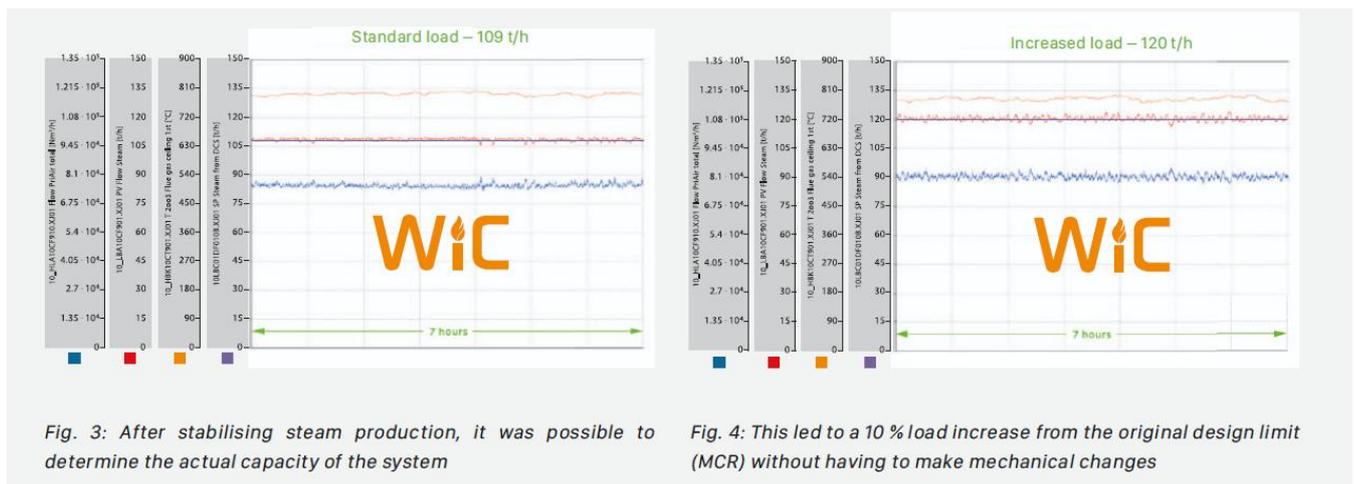
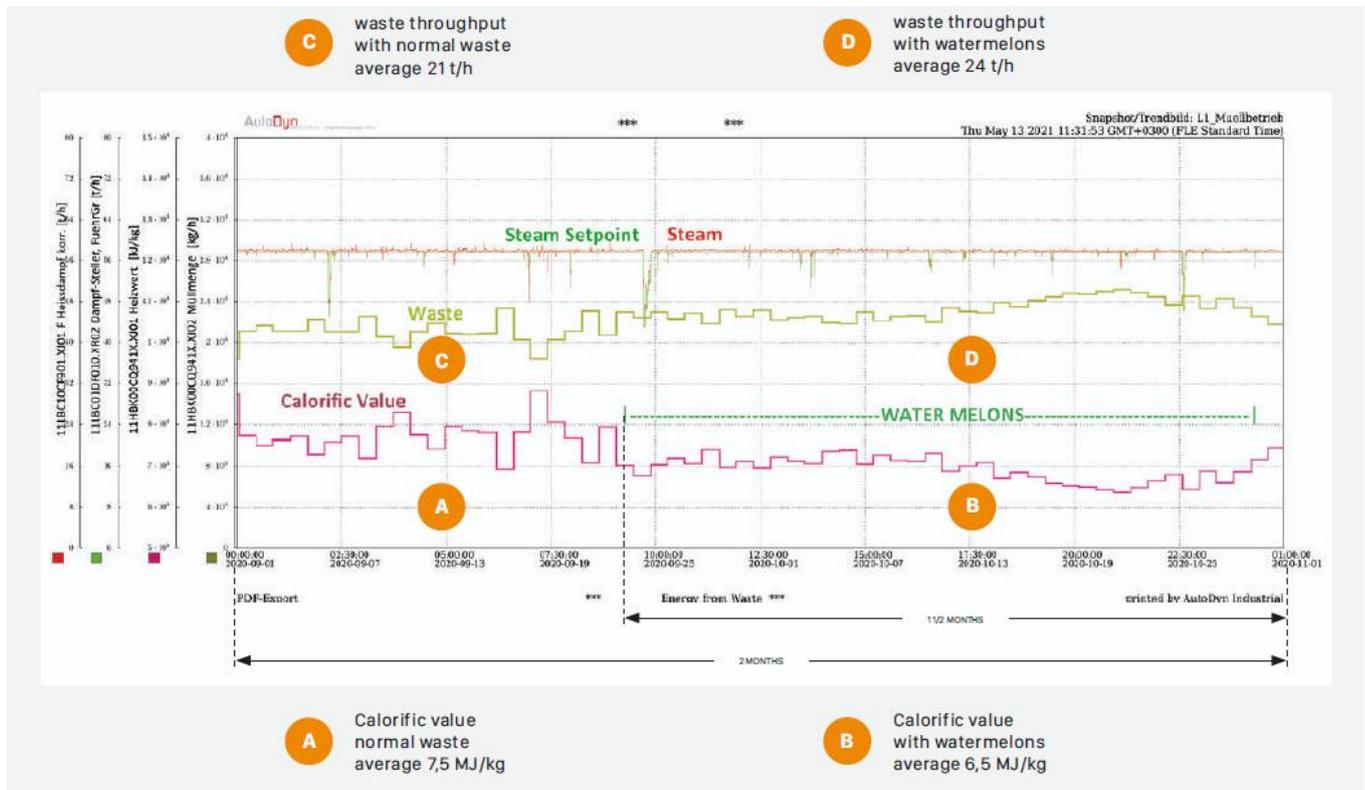


Fig. 3: After stabilising steam production, it was possible to determine the actual capacity of the system

Fig. 4: This led to a 10 % load increase from the original design limit (MCR) without having to make mechanical changes

On diagram below described is case story about combustion of low calorific fule



## Discussion / Conclusion

Appropriate combustion control on forward moving reciprocating grates can have considerable positive impact on reliability, availability and profitability of biomass to energy and waste to energy plants.

TECHNIKGRUPPE has interest for cooperation with **universities on projects for improvement of combustion processes on plants. Technikgruppe technical experts** can provide FREE plant inspections and education of university and industrial personal. IF estimation is that implementation of combustion optimisation on **PARTICULAR COMBUSTION LINE** can have positive impact TECHNIKGRUPPE can provide FREE (TEMPORARY) TEST INSTALLATION .

[www.technikgruppe.com/technology-of-fire](http://www.technikgruppe.com/technology-of-fire)

**Keywords:** keyword

Combustion optimisation  
Enhancement of incineration capacity  
Forward moving reciprocating grate  
Steam production stabilisation  
Generator output stabilisation

## **Full year analysis of particle removal and heat recovery in a district heating system using a Module-based simulation model and process data.**

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Leteng Lin<sup>1</sup>

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### **Introduction**

While wood chip combustion is an established and efficient carbon-neutral source for district heating [1], it generates particulate matter with severe health implications [2]. Medium-scale facilities typically use cyclones for particle removal due to their low installation and operational costs; however, cyclones exhibit poor efficiency for particles smaller than 5  $\mu\text{m}$ . This limitation challenges compliance with stricter 2018 EU regulations, which cap emissions at 50  $\text{mg}/\text{Nm}^3$  for 1–5 MW facilities and 30  $\text{mg}/\text{Nm}^3$  for 5–20 MW facilities [3]. Wet scrubbers offer superior particle removal, and when integrated with heat recovery, the high operational costs associated with high-pressure scrubbing can be effectively offset [4]. Although particle removal in the submicron sizes are still challenging for wet scrubbers, several studies have shown that this can be remedied by increased mass- and heat flows between gas and droplets [5, 6].

In earlier work we have developed a module-based simulation model which have shown good prediction capacity regarding particle removal and heat recovery [7, 8]. When analysing the particle removal phenomena, increased gas temperature and reduced scrubber water temperature were highlighted as possible ways to increase particle removal further. In this paper, we have used process data from a full year to investigate particle removal and heat recovery at a district heating boiler in Kosta, using our MBS-model.

### **Methodology**

Figure 1 shows a flow chart of the MBS-model. The model has been further explained and validated in previous papers [7, 8], so in this we will just briefly explain the different modules. First, droplet simulations of a set number of droplets are performed in a two-dimensional mesh, establishing a mass-balance of droplets throughout the scrubber. In the second module, a mass- and energy balance is performed between droplets and gas, accounting for radiation, convection and condensation. The energy balance is first established against an estimated flue gas temperature distribution which is then updated according to the calculated mass- and heat flows. The new temperature distribution is then used for a new mass- and energy balance with respect to the droplets. This process is then iterated until a set convergence criterion is fulfilled. Finally, the output from Module 1, and 2 are used to simulate the particle removal throughout the scrubber.

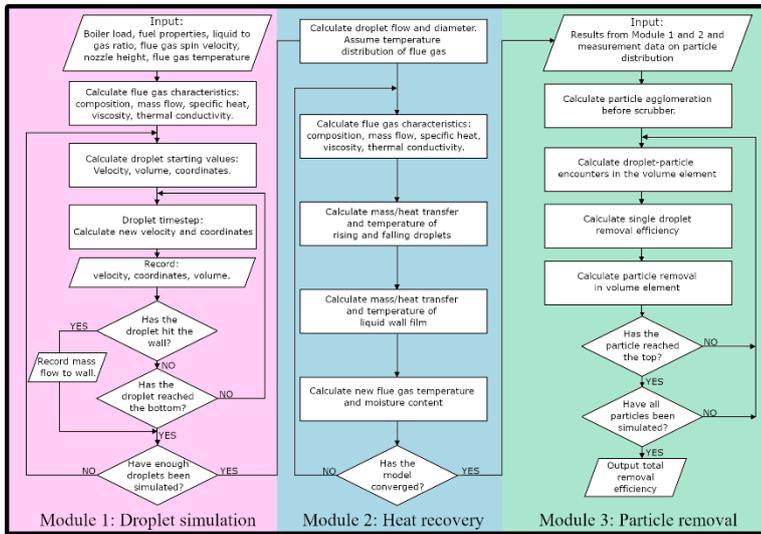


Figure 1: Flowchart of simulation model

In this work, the model was used to investigate the synergies and trade-offs between heat recovery and particle removal when adjusting flue gas- and water temperatures. This was performed by running a single validated scenario and changing one parameter at a time. To increase the flue gas temperature, it is assumed that the gas is removed earlier from the boiler. Naturally, this would shift some energy from the boiler to the scrubber and is expected to lower the system efficiency since less heat exchanger area is used in total. To account for this, the net heat recovery is calculated with Eq. 1:

$$\dot{Q}_{net} = \dot{Q}_{Scrubber} - \dot{m}_{gas} C_{p_{gas}} (T_{high} - T_{ref}) \quad (1)$$

where  $\dot{Q}_{Scrubber}$  is the heat recovery in the scrubber,  $\dot{m}_{gas}$  is the flue gas mass flow,  $C_{p_{gas}}$  is the specific heat of the gas,  $T_{high}$  is the gas temperature in the scrubber inlet in the high temperature scenario, and  $T_{ref}$  is the gas temperature in the scrubber inlet in under normal operating conditions.

Using the results from the process analysis, 3 scenarios were chosen to investigate through a full year analysis. One base scenario using current operations and two optimized scenarios according to the earlier mentioned investigation. The input for the model in each scenario is shown in Table 1

Table 1: Input to simulation model for full year analysis

	Base case	Optimized Scenario 1	Optimized Scenario 2
Gas temperature to scrubber(°C)	Process data	Process data	300
O2-value in flue gas (%)	Process data	Process data	Process data
Temperature of return water (°C)	Process data	25	25
Heat demand (MW)	Process data	Process data	Process data
Water pressure (Bar)	8	8	8
Fuel moisture content (%)	50	50	50

The boiler load was calculated according to Eq. 2. However, since the boiler load will also affect the heat recovery, the simulation was iterated until the values converged.

$$P_{boiler} = P_{demand} - P_{scrubber} \quad (2)$$

Where  $P_{boiler}$  is the boiler load,  $P_{demand}$  is the district heating demand, and  $P_{scrubber}$  is the recovered heat calculated by the MBS-model.

## Results

Figure 2a shows the particle removal and heat production as a function of flue gas temperature as compared to the base values at high and low boiler load. As the temperature increases, the net heat recovery decreases. This is due to the scrubber not being able to cool down the gas as much when the incoming temperature increases. This effect is significantly larger for the high load scenario, compared to the low-load scenario. This indicates that the issue could be resolved by increasing scrubber size and/or water pressure. However, for both cases, particle removal increases significantly more than the heat recovery decreases. This can be explained by the thermophoresis being the driving force for particle removal in the fine mode. In Fig. 2b, we can observe that a decrease in water temperature increases both particle removal and heat recovery which is mainly an effect of increased condensation in the scrubber. Finally, in Figure 2c the scrubber water is fixed at 20 degrees while flue gas temperature increases. In this case, we see that both particle removal and heat recovery is higher than the baseline, with a maximum submicron particle removal at 40 %.

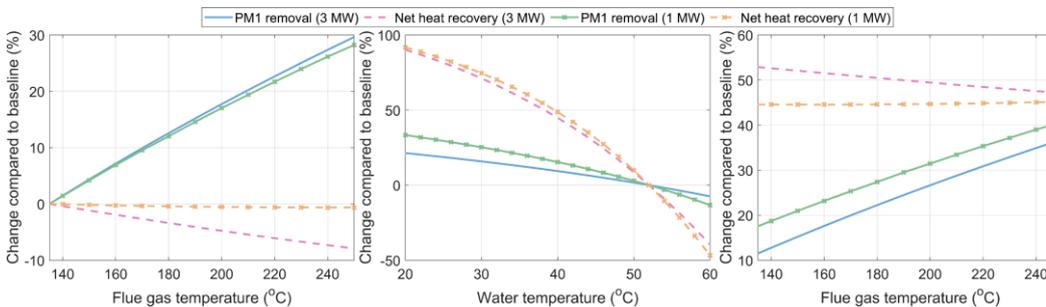


Figure 2: Particle removal and net heat recovery as correlated to a) flue gas temperature b) water temperature, and c) flue gas temperature when the water temperature is lowered to 20 C.

Figure 3 shows the simulated particle removal of submicron particles for different scenarios. While the PMI removal varies between 25 – 45 % for the reference scenario, both the optimization scenarios showed a possibility to increase both removal and heat recovery. As expected, the combined approach with an increased gas temperature and reduced water temperature showed most promise regarding particle removal but gave a lower increase in heat recovery. As expected, in all scenarios, high load correlated with lower particle removal. This is important since this would

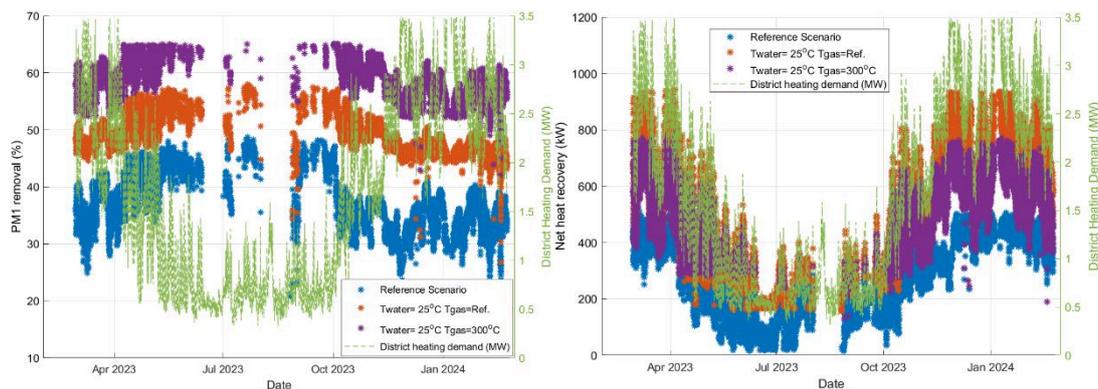


Figure 3: Full year performance analysis of wet scrubber

## Conclusion

This work demonstrates the effectiveness of the Module-based simulation (MBS) model in optimizing district heating systems for both energy efficiency and emission control. The results indicate that process parameters play a critical role in the performance of wet scrubbers. Specifically, lowering the scrubber water temperature emerged as a beneficial strategy, simultaneously enhancing heat recovery and particle removal through increased condensation. Furthermore, while increasing the flue gas inlet temperature results in a trade-off regarding net heat recovery, it significantly improves submicron particle removal through thermophoresis. By combining the two approaches, high particle removal could be achieved while maintaining significant heat recovery.

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Keywords: Particle removal, Waste heat recovery, Flue gas condenser, District heating

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## **Decarbonization of DH systems in Lithuania and Kretinga District Municipality**

Dr. Eugenija Farida Dzenajavičienė<sup>1\*</sup>

Dr. Rimantas Bakas<sup>1</sup>

<sup>1</sup> Lithuanian Energy Institute

### **Abstract**

Currently Lithuania has reached nearly 90% goal of using biomass for district heating. However, it is still dealing with the new challenges on development of new technological solutions, related to improvement of energy efficiency and wider use of renewable and waste energy. Assessment of such solutions in technological, economic and environmental terms plays the key role for further decarbonization of district heating sector. Besides, the role of sector digitalization is becoming extremely important for improvement of system efficiency. It also shows the need for financial support, necessary for implementation of new technologies, especially in smaller municipalities with lack of own funds.

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## **Decarbonisation with simultaneous improvement of heat supply and utilisation efficiency in the district heating system in Łomża**

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<sup>1</sup>Institute of Fluid Flow Machinery, Polish Academy of Sciences (IMP PAN)

### **Abstract**

The article presents a new methodology that focuses on modernising heat sources and simultaneously improving the actual energy efficiency of the entire district heating system. It is based on a newly developed heat transfer model in exchangers, heating substations and the entire DHS system. The implementation of this methodology in Łomża (representing a typical DHS system) has made it possible to reduce the supply temperature (from 121°C to 96°C throughout the system, led to a 30% reduction in heat losses, coal demand and CO<sub>2</sub> emissions, and increased heat exchange efficiency in buildings, hydraulic network stability and improved working conditions in the combined heat and power and heating plant.

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## ***Reprogramming Space: Spatial Sufficiency in Single-Family Housing*** *Socio-material conditions for demand reduction in existing housing stocks*

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Brijesh Mainali<sup>1</sup>  
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Reducing energy demand and resource use in the building sector is widely recognised as central to climate mitigation in high-income countries. Nevertheless, decades of policy emphasis on energy efficiency, low-carbon technologies, and material substitution have not resulted in proportional reductions in absolute emissions. One explanation lies in the continued expansion of residential floor area, rising housing standards, and the increasing financialisation of housing, which together stabilise resource-intensive systems of housing provision and use. These developments point to the limits of efficiency-oriented approaches and motivate growing interest in sufficiency as a strategy concerned with reducing demand rather than optimising supply.

Within housing research, however, sufficiency remains weakly specified and poorly operationalised. While the concept implies questioning spatial standards, occupancy intensity, and dominant assumptions about dwelling size, empirical studies have frequently framed sufficiency as a matter of individual lifestyle choice, voluntary restraint, or downsizing decisions. Such approaches tend to obscure the extent to which housing practices are shaped by material arrangements, institutional frameworks, and professional routines, and they provide limited insight into how sufficiency-oriented practices might be enabled or constrained within existing housing systems.

This study approaches spatial sufficiency as a question of socio-material organisation rather than individual behaviour. It conceptualises sufficiency as a process of reprogramming existing housing arrangements—that is, modifying the material and institutional configurations through which housing practices are performed, without relying on large-scale replacement or new construction. Reprogramming is used as an analytical lens to examine how existing housing stocks are configured to sustain low-occupancy, space-intensive living, and how limited spatial and institutional adjustments may enable alternative, less resource-intensive practice performances.

Empirically, the paper draws on focus-group workshops with owners of single-family houses conducted in Sweden in late 2022. The Swedish single-family housing stock constitutes a relevant empirical case due to its high residential floor area per capita, low occupancy density, and strong cultural association with privacy, autonomy, and exclusive use. Much of this stock was produced under socio-demographic conditions characterised by larger households and stable family structures, conditions that no longer prevail. As household sizes decline, existing dwellings increasingly accommodate fewer occupants while maintaining the same conditioned space, contributing to high per-capita energy use and material demand.

The focus groups were structured around concrete scenarios of spatial change, including internal subdivision, intensified use of underutilised rooms, sharing arrangements, and the creation of additional self-contained dwellings within existing houses. Rather than eliciting attitudes or preferences, the analysis examines how participants articulate, negotiate, and problematise these scenarios in relation to prevailing material configurations, property regimes, regulatory frameworks, and everyday expectations of domestic life.

Housing is analysed as a material arrangement that coordinates multiple practices related to living, privacy, comfort, and value, rather than as a neutral container for individual choice.

The analysis shows that spatial sufficiency measures are rarely rejected on environmental grounds. Instead, resistance is primarily linked to how existing housing arrangements are programmed to support particular forms of living. Participants commonly associated spatial reconfiguration with loss of autonomy, reduced flexibility, and potential devaluation of property, indicating that dominant housing norms play a central role in stabilising space-intensive practices. Environmental awareness was widespread among participants, yet it had limited influence on the perceived feasibility of spatial change when such change conflicted with established material and institutional arrangements.

At the same time, the findings demonstrate that these arrangements are not immutable. Acceptance of spatial reprogramming increased when interventions were framed as reversible, economically rational, and supported by professional intermediaries capable of managing technical, regulatory, and organisational complexity. Potential rental income and reductions in operating costs were frequently cited as more convincing justifications than environmental arguments alone. These observations highlight the importance of renovation systems, regulatory frameworks, and professional practices in shaping the conditions under which sufficiency-oriented housing practices may emerge.

From a practice-theoretical perspective, the findings suggest that the limited uptake of spatial sufficiency in single-family housing is not primarily a question of individual motivation or awareness, but of how existing socio-material arrangements stabilise particular practice performances. Housing stocks, renovation routines, and property logics are currently configured to reproduce space-intensive living, rendering sufficiency difficult to perform within everyday life. Reprogramming thus operates both as an analytical concept and as a potential intervention strategy, directing attention to points where relatively modest changes to existing arrangements may have disproportionate effects on resource use.

The paper concludes that advancing spatial sufficiency in single-family housing requires a shift away from behaviour-centred approaches toward interventions that target the material and institutional organisation of housing provision. By embedding spatial reconfiguration within renovation systems that reduce risk, lower transaction costs, and align with everyday practices, sufficiency-oriented housing practices may become feasible within the existing building stock. Rather than asking whether sufficiency is desirable, the analysis reframes the issue as one of how housing systems can be reprogrammed to make sufficiency practicable under current conditions

*Keywords:* space sufficiency, practice theory, reprogramming, single-family house, renovation

## **The Role of Information and Communication Technology in Enabling Lifecycle Management for the Circular Economy in the Built Environment**

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### **Introduction**

The built environment is responsible for extensive raw material use, high energy consumption, and significant waste generation. The Circular Economy (CE) has gained prominence as a response to the environmental impacts of the linear production (Goyal et al. 2018). Life Cycle Management (LCM) supports CE by assessing environmental, economic, and social impacts across a product's full life cycle (Itskos et al. 2016). It can enable decision-making through standardized indicators and systematic data analysis.

Digital technologies are increasingly recognized as enablers of CE. These tools enhance supply chain transparency, resource efficiency, and material traceability, and support innovative Product-Service Systems. Despite growing interest, the specific role of ICT in CE-oriented lifecycle management, particularly in construction, remains underexplored.

Existing studies have addressed CE challenges in construction, barriers to adopting digital technologies (Thirumal et al., 2024), and some ICT-based decision support tools (Yu et al., 2023). However, gaps remain in understanding how ICT can support CE practices throughout the entire building lifecycle.

To address this gap, the present study formulates the following research questions:

1. What are the key ICT and platforms that have been employed in advancing CE practices and enhancing life cycle analysis methodologies in the construction industry?
2. How have these ICTs been applied in different contexts of CE in the construction sector?
3. What are the barriers to leveraging ICT for advancing CE practices and enhancing life cycle management in the built environment?
4. What are the opportunities for implementing ICT for CE initiatives in lifecycle management?

### **Methodology / Approach**

This study employed a Systematic Literature Review to identify, evaluate, and synthesize existing research on ICT applications in circular economy (CE) and life cycle management (LCM) within the construction sector. This process involved three key stages: identifying academic journal articles, selecting closely related publications, and performing a detailed content analysis.

### Step 1: Literature Search

The review relied exclusively on the Scopus database due to its broad coverage and reliability. A carefully constructed search string combining CE, LCM, ICT, and construction-related terms was applied within article titles, abstracts, and keywords.

### Step 2: Literature Selection

The initial search yielded 239 publications. After screening titles and abstracts, applying exclusion criteria (English language, publication years 2019–2024, peer-reviewed articles), and conducting a full-text relevance check, 30 studies were identified as directly relevant to CE, ICT, LCM, and the built environment.

### Step 3: Content Analysis

Selected studies underwent a structured content analysis to identify trends, conceptual developments, applied technologies, and research gaps. Publications were categorized according to lifecycle stages of construction using an established lifecycle-based framework.

## Results / Discussion

The findings reveal a steady growth in research on ICT-enabled LCM to advance CE practices within the built environment. Descriptive analysis indicates that the life cycle management approach is predominantly applied during the design and pre-construction stages, where early interventions have the greatest influence on resource efficiency and waste reduction. The end-of-life stage is the next most explored, particularly in relation to material recovery and waste management from construction and demolition activities. Among CE principles, reduce, reuse, and recycle are prominently reflected across the reviewed literature.

Across the reviewed studies, Building Information Modelling (BIM) emerges as the most widely adopted ICT tool, supporting decision-making, material tracking, environmental modelling, and design for deconstruction (Zanni et al. 2019; Xing et al. 2020; Saleh et al. 2024). GIS facilitates spatial and temporal analyses of material flows at regional scales and supports logistics planning, environmental impact assessment, and lifecycle-based decision-making (Aldebei and Dombi, 2021; Keena et al. 2023; Kushch et al. 2024; Kuzminykh et al. 2024). RFID technology plays an equally important role in real-time resource monitoring by enabling material traceability throughout the supply chain. RFID systems support dynamic data collection for logistical planning and incident management, helping to minimise production waste and enhance CE implementation (Turner et al. 2021; Vahidi et al. 2024; Kuzminykh et al. 2024). IoT, AI, and Machine Learning are increasingly applied for real-time performance monitoring, predictive maintenance, and supply-chain transparency, although their adoption remains less mature. Emerging technologies, like Big Data Analytics and Blockchain, show significant potential but are not yet widely implemented.

Content analysis highlights three major opportunity areas enabled by ICT:

- Enhanced information sharing and decision support: ICT tools are crucial for supporting Life Cycle Management in the built environment by enabling CE-aligned decision-making and efficient information exchange (Yu et al., 2022; Demestichas & Daskalakis, 2020). However, fragmented data sharing among stakeholders remains a major barrier to integrated and optimized CE strategies (Kovacic et al., 2020). Digital platforms, BIM, and IoT help overcome this challenge by facilitating lifecycle data flow, stakeholder collaboration, and resource-efficient planning across all project

phases (Rezaei et al., 2019; Kuzminykh et al., 2024).

- **Environmental benefit:** ICT plays a key role in enabling circularity across all building lifecycle phases by supporting material optimization and early-stage decisions that reduce long-term resource use and emissions (Takyi-Annan & Zhang, 2023; Kovacic et al., 2020; Sameer & Bringezu, 2021). Digital tools such as BIM enhance circular design, enabling strategies like reuse, recycling, and design-for-deconstruction, while also simplifying environmental assessment through integrated LCA tools (Akanbi et al., 2019; Sameer & Bringezu, 2021). During operation, IoT and AI support real-time monitoring and predictive maintenance, improving resource efficiency and extending building and component lifespans (Kushch et al., 2024).
- **Increased productivity and efficiency:** BIM has become a key ICT solution for addressing long-standing challenges in construction, such as low productivity, poor predictability, and high waste; while supporting the uptake of circular economy (CE) principles (Davila Delgado & Oyedele, 2020). Its ability to manage detailed material data across the asset lifecycle enables resource optimization, traceability, and CE implementation (Atik et al., 2024; Charef et al., 2021).  
As a collaborative platform, BIM enhances data sharing and can integrate with big data and IoT systems to improve transparency across the value chain (Abruzzini & Abrishami, 2022; Giovanardi et al., 2023). IoT-enabled monitoring and predictive maintenance further increase efficiency, lower lifecycle costs and carbon footprints, and reduce construction waste, reinforcing CE practices (Charef et al., 2021; Figueiredo et al., 2021; Eftekhari et al., 2024).

Despite these opportunities, several challenges hinder widespread ICT adoption:

- **Technical barriers:** The complexity of building processes and fragmented, non-standardized data make ICT integration difficult (Çetin et al., 2021; Keena et al., 2023). Insufficient BIM standards and persistent issues with outdated or inaccurate lifecycle data impede effective CE modeling and asset monitoring (Davila Delgado & Oyedele, 2020; Abrishami & Abruzzini, 2021).  
there is a notable gap in comprehensive studies assessing the long-term environmental impacts of BIM-AI integration and in optimizing AI algorithms for application in varied AEC (Architecture, Engineering, and Construction) contexts. This contributes to the ongoing difficulty of integrating BIM, AI, and IoT technologies across all phases of construction projects (Saleh et al. 2024).
- **Data availability:** A lack of complete and up-to-date footprint and lifecycle data limits accurate environmental analysis and circularity assessments, highlighting the need for improved LCA databases and standardized data structures (Sameer & Bringezu, 2021; Kuzminykh et al., 2024). Existing tools often fail to integrate multiple performance metrics, restricting holistic CE decision-making (Keena et al., 2023).  
BIM data is frequently outdated or incomplete, reducing trust in as-built information (Abruzzini & Abrishami, 2022; Charef et al., 2021). Fragmented markets and difficulties in collecting and organizing lifecycle data further hinder CE implementation (Giovanardi et al., 2023).
- **Organizational and collaboration challenges:** systemic industry barrier, limit digitalisation for circular construction, making stakeholder collaboration essential (van den Berg et al., 2020; Soust-Verdaguer et al., 2024). Collaboration gaps, fragmented information flows, and logistical challenges hinder effective CE implementation and reuse practices (Kushch et al., 2024; Kuzminykh et al., 2024; Keena et al., 2023). Resistance to the adoption of digital technologies such as BIM and AI also persists, largely due to a lack of awareness, training, and familiarity among professionals (Saleh et al., 2024).

## Conclusion

This study conducted a systematic literature review to examine how Information and Communication Technologies (ICT) enable lifecycle management (LCM) in advancing Circular Economy (CE) practices within the built environment. Analysis of 30 selected studies shows increasing research attention on ICT-driven circularity in recent years. Building Information Modelling (BIM) emerged as the most widely applied technology, particularly during the early design and pre-construction stages—where lifecycle decisions have the greatest potential to influence circular outcomes.

The review identified three main benefits of ICT-enabled LCM:

- Enhanced information sharing and decision support, enabling improved coordination and transparency across stakeholders.
- Environmental benefits, including early optimisation of material use, reduced waste, and improved resource recovery.
- Increased productivity and efficiency, supported by better data management, predictive capabilities, and process integration.

However, several barriers hinder ICT adoption for CE, grouped into technical, data-related, and organisational/collaboration challenges. Addressing these limitations through targeted research, improved standards, and supportive policy frameworks is essential for enabling more effective digital integration and accelerating CE transformation in the built environment.

**Keywords:** Lifecycle management; Information and communication technologies; Circular economy; Built environment.

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## **Assessing consumer behaviour on purchase, use life and handling at end of use life in context of circularity of furniture**

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### **Introduction**

Wood furniture occupies a central role in transformation of furniture sector towards meeting sustainability targets because wood is a renewable material with inherent potential for circularity (i.e., reuse, repair, recycling) when correctly managed. However, understanding how long wood furniture is used in practice (its use life) and how public perceptions influence its longevity is critical to realizing this potential. Hence, monitoring consumer purchasing behaviour particularly their preferences and attitudes has long been recognized as a critical factor influencing the success and advancement of various industries, including wood furniture manufacturing (Pirc Barčić et al., 2021). From a circular-economy perspective, extending the service life of furniture is crucial. Durable and ecodesigned furniture reduces the need for frequent replacement and thereby lessens resource extraction, carbon storage, waste generation, and greenhouse gas emissions over time (Sabbir, 2025). Product features and designed lifespan act as quality indicators that significantly affect consumers' adoption of eco-friendly furniture.

Beyond the technical and design dimensions, consumer behaviour and public perceptions play a pivotal role in shaping the life cycle of furniture. For instance, recent studies of user perspectives show that circular value propositions (e.g., reuse and sharing) are influenced by both environmental motivations and perceived barriers, such as the quality of pre-owned products (Hagejård et al., 2025). Moreover, literature reported on sustainability assessment of furniture manufacturing emphasize that design for repair, reconditioning, and disassembly can extend product life and thereby mitigate resource scarcity, extend carbon storage, enhance sustainability and reduce climate impact (Krystofik et al., 2018; Tessitore et al., 2025; Wassholm & Moussa, 2025).

Despite increasing industry and policy support for circular business models in furniture, there is limited empirical evidence linking public attitudes toward sustainability, circularity, and climate impact with actual use duration of wood furniture. Existing literature lacks robust data on “use-phase behaviour,” specifically how long consumers retain and discard wooden furniture in the context of circular economy objectives. In this context, the present study aims to examine how public behaviour influences the purchase, use, and end-of-life handling of wood furniture, with a particular focus on the role of sustainability and environmental perceptions. This study investigates consumers' furniture purchasing behaviours, their expectations regarding the service life of furniture, and the ways in which they manage furniture at the end of its useful life.

This study employed a web-based survey to record self-reported consumer behaviour, attitudes, and demographics to generate empirical insights relevant to circular design, policy, and business models in the wood furniture sector. The research contributes to existing literature by providing quantitative evidence on furniture use duration, complementing life cycle assessment studies that rely on assumed lifespans. It also links

furniture use-life with consumer perceptions of circularity and environmental impact, highlighting behavioural drivers and barriers to circular transitions. Finally, the findings offer practical implications for designers, manufacturers, and policymakers aiming to improve furniture durability, affordability, and the effectiveness of local second-hand furniture systems.

## Methodology

In this pilot scale survey, a web-based questionnaire link and QR code with an explanatory note was distributed in Sweden and globally via email, digital social median (LinkedIn, Facebook) network to engage the wider public. Furthermore, the QR code was printed and displayed on notice boards across Linnaeus University to reach students, faculty, and staff.

## Results and discussion

### Socioeconomic data of respondents

Table 1. Description of the socio-economic and demographic characteristics of respondents.

	Gender and relationship status		Highest level of education		
	Sweden (n=43)	Global (n=62)		Sweden (n=44)	Global (n=62)
Male	42%	50%	University or college	71%	98%
Female	58%	50%	High School or gymnasium	5%	0%
Civil partnership - Yes	65%	65%	Primary school, secondary school or similar	25%	2%
Civil partnership - No	35%	36%			
	Do you live		Age category		
	Sweden (n=44)	Global (n=61)	Age (Years)	Sweden (n=44)	Global (n=62)
In a city	16%	66%	Less than 30	19%	24%
In town and semi-dense area	71%	26%	31 - 40	35%	34%
In a rural area	14%	8%	41 - 50	30%	23%
			51 - 60	5%	16%
			More than 61	12%	3%

## Purchasing used furniture

The survey results show (Figure 1) that Swedish respondents are, on average, 23.3% more likely to purchase used furniture than global respondents, indicating a higher acceptance of second-hand furniture in Sweden, likely due to better market availability and accessibility. However, acceptance varies by product type. Both Swedish and global respondents show low willingness to purchase used beds, with only 19% acceptance, suggesting a higher disposal tendency for this item. In contrast, over half of Swedish respondents are willing to buy used display cabinets and chests, while acceptance for these items among global respondents is significantly lower.

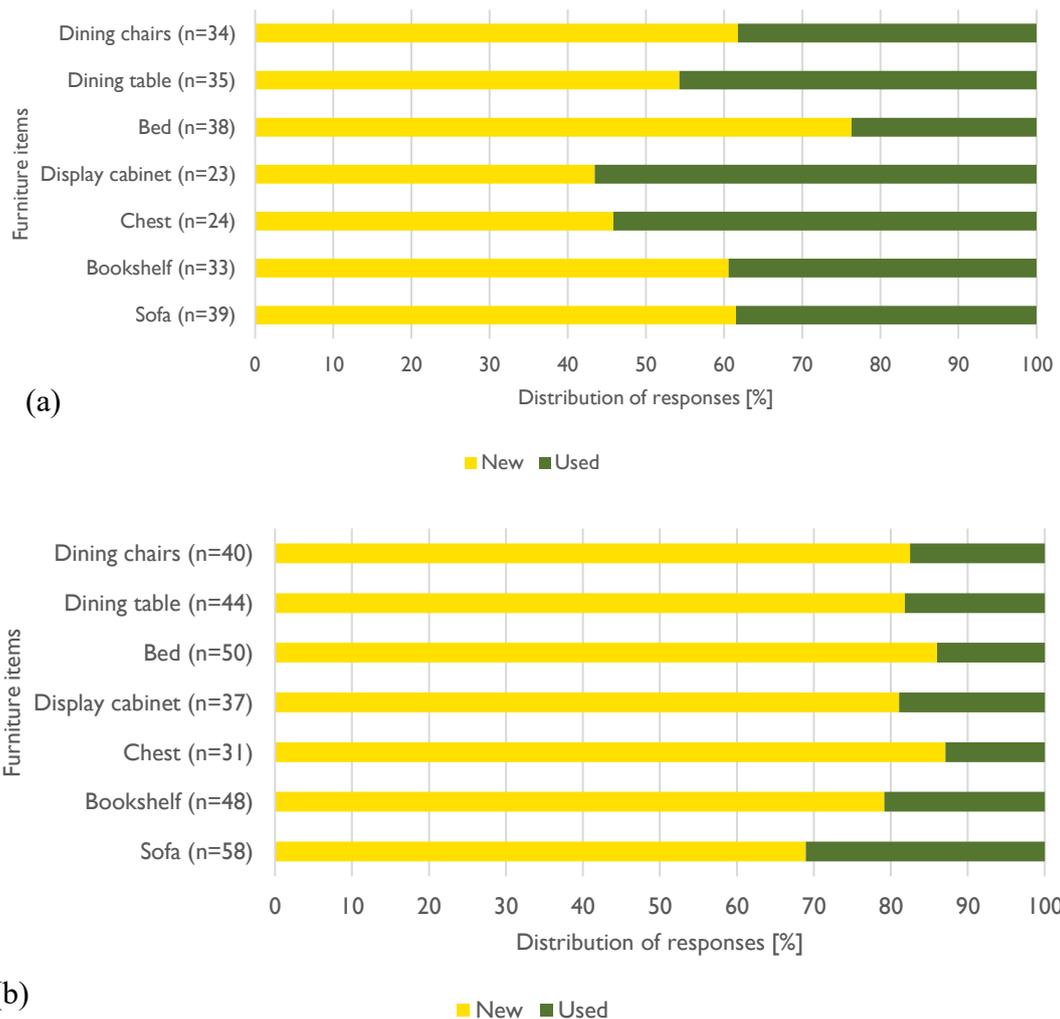


Figure 1. Distribution of responses on acquiring used furniture (a) Sweden and (b) Global.

## Influencing factor in acquiring used furniture

The survey examined the reasons behind purchasing used furniture and found that “good value for money” is the primary motivating factor, strongly agreed upon by 64% of Swedish respondents and 48% of global respondents (Figure 2). Sustainability is the second most influential factor for global respondents, while Swedish respondents rank emotional or sentimental value as the second most important reason for acquiring used furniture.

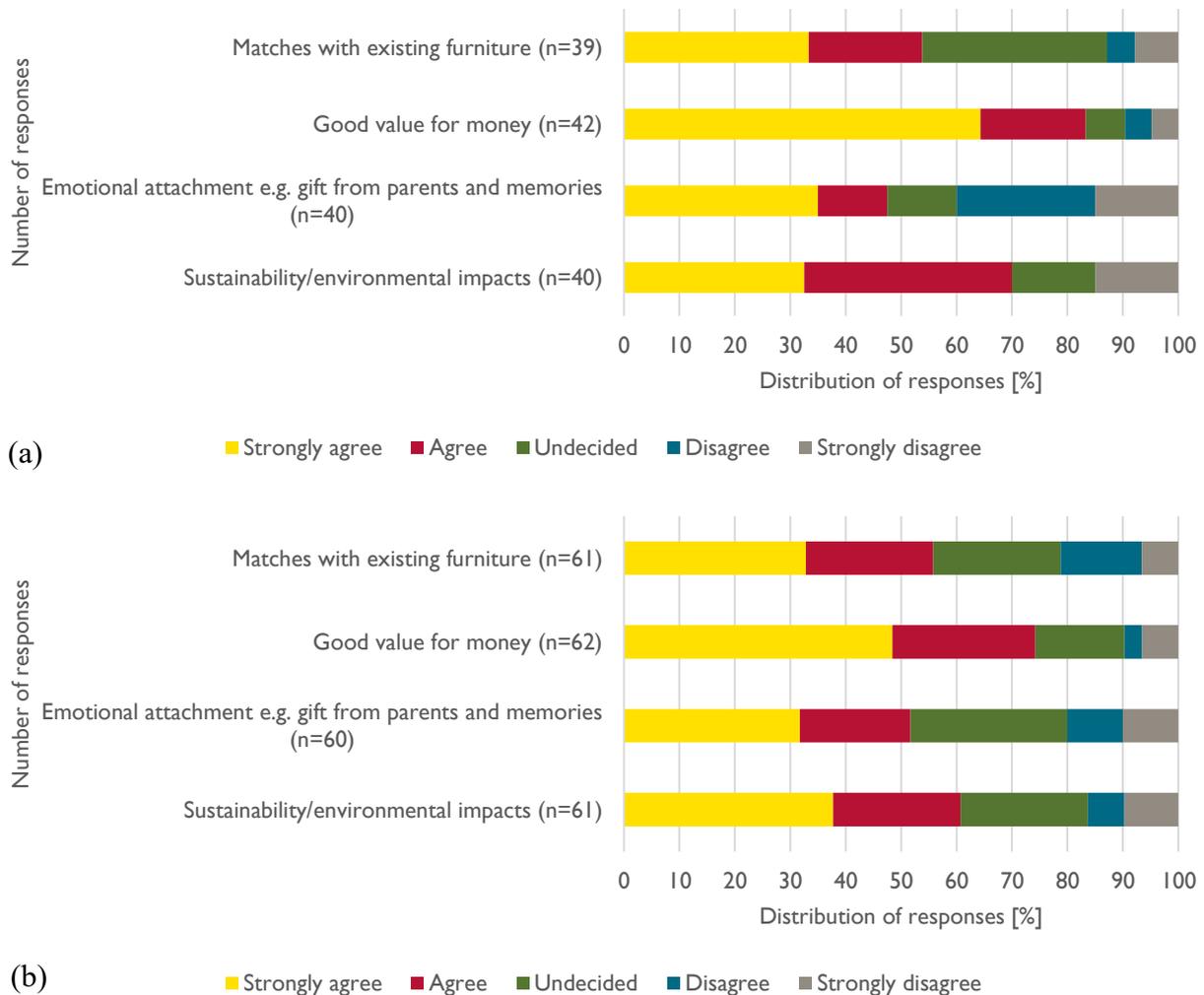
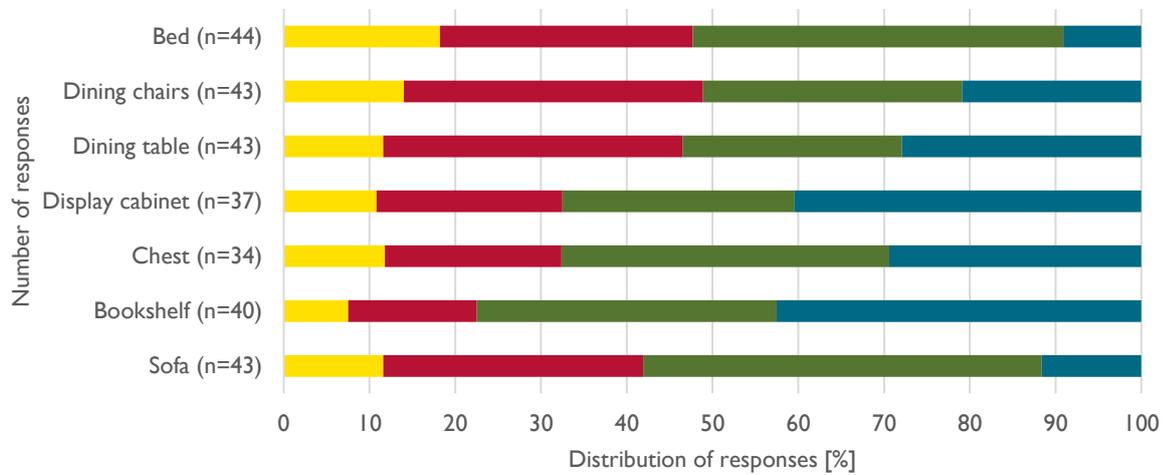


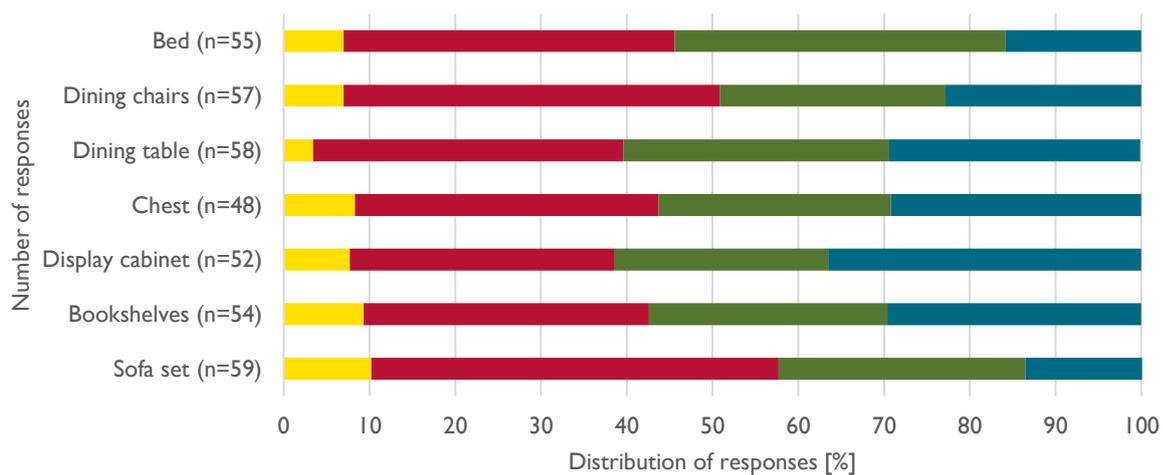
Figure 2. Influencing factor in acquiring used furniture (a) Sweden and (b) Global.

### Expected service life of furniture

Survey results on expected furniture lifespan show that Swedish respondents anticipate longer use of bookshelves and display cabinets, with 43% and 41%, respectively, expecting a lifespan exceeding 20 years (Figure 3). Global respondents also expect longer lifespans for these items, particularly display cabinets (37%), though at slightly lower levels than in Sweden. Among Swedish respondents, chests rank third in expected longevity, with 67.6% anticipating use for 10–20 years or longer, followed by sofas at 57%. Overall, the findings indicate that expected furniture lifespan varies by item type, reflecting differences in function and intended use.



(a) ■ Less than 5 years ■ 5-10 years ■ 10-20 years ■ More than 20 years

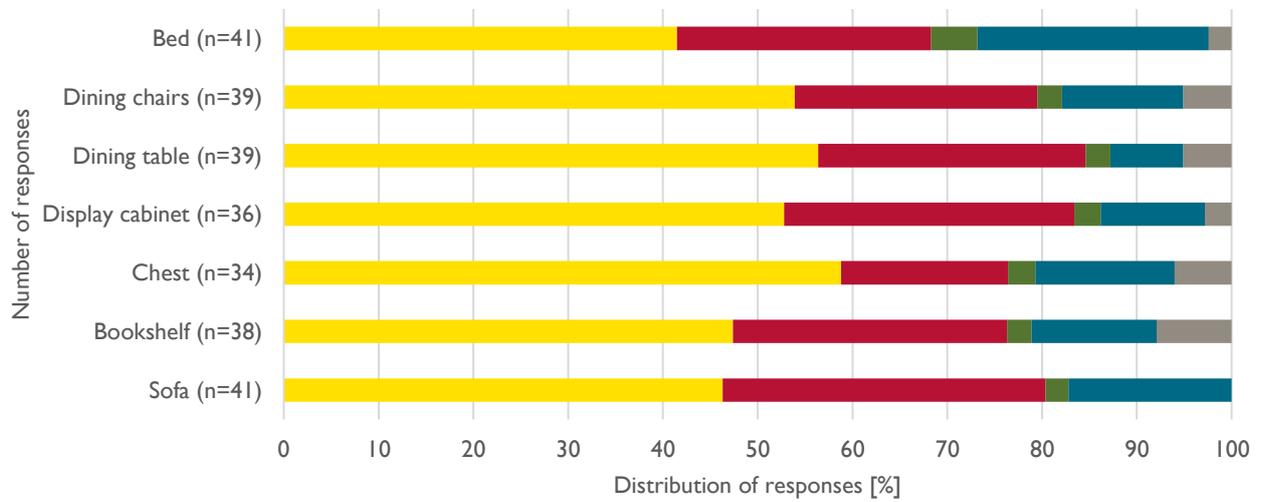


(b) ■ Less than 5 years ■ 5-10 years ■ 10-20 years ■ More than 20 years

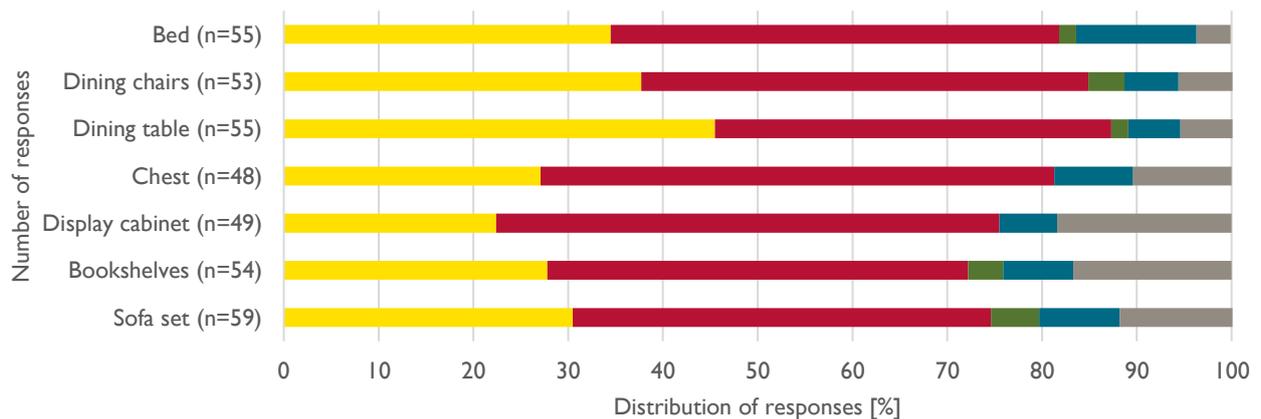
Figure 3. Expected use of furniture (a) Sweden and (b) Global.

### Handling of furniture at end of use

The survey results show (Figure 4) that among Swedish respondents, selling is the most common method for handling furniture no longer in use, ranging from 41.5% for beds to 58.8% for chests, reflecting a well-established resale market supported by online platforms and second-hand stores. Globally, selling ranks second, with lower response rates across items. Donation is the primary end-of-use option globally (41.8%–54.2%), while it is the second most common choice in Sweden. Collectively, selling and donation are the dominant handling methods in both surveys. Additionally, a higher proportion of Swedish respondents report taking furniture to recycling centers (7.7%–24.4%) compared with global respondents (5.55%–13.2%), indicating stronger recycling practices and greater consumer engagement with sustainable end-of-life furniture management in Sweden.



(a) Sell Donate Leave at the nearest garbage bin Take to the recycling center Place in my storage room/garage



(b) Sell Donate Leave at the nearest garbage bin Take to the recycling center Place in my storage room/garage

Figure 4. Handling of furniture at the end-of-use (a) Sweden and (b) Global.

## Conclusions

The survey results show that Swedish respondents are generally more accepting of purchasing used furniture than global respondents, which can help extend furniture service life. Acceptance of reuse varies by product type: beds have low acceptance (23% in Sweden and 14% globally), while items such as display cabinets and chests of drawers show much higher acceptance among Swedish consumers. Income is a key factor influencing purchasing behaviour, with higher-income respondents preferring new furniture and lower-income respondents more willing to buy used items. Value for money is the main motivation for purchasing used furniture, although sustainability and emotional considerations also play a role.

Furniture usage patterns indicate shorter expected service lifespan for bed and sofa compared to items like cabinets, tables, and chairs, which are more often reused. End-of-life behaviour is shaped by acceptance of second-hand furniture and local waste management systems. Swedish respondents are more likely to sell furniture after use, reflecting stronger second-hand markets and contributing positively to furniture circularity.

Further research with a larger and more diverse sample is recommended to better understand consumer behaviour across regions.

*Keywords:* climate change, life cycle, wood recycling, biogenic carbon, end-of-life, greenhouse gas emissions

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# From Vision to Action: Expert-Driven Backcasting Toward a Circular and Climate-Neutral Built Environment by 2050

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## Introduction

The transition toward a circular and climate-neutral construction sector is critical to achieving the EU 2050 goals. Especially, when the construction sector accounts for approximately 40% of global resource consumption and 36% of greenhouse gas emissions. Achieving circularity and net-zero emissions by mid-century requires not only technical innovation but also regulatory, economic, and cultural realignment across value chains. Current regulatory frameworks and market practices remain largely linear, with limited integration of life-cycle carbon performance and circularity principles. This study explores how a shared long-term vision can guide systemic transformation, using participatory foresight and expert validation to define measurable pathways for the sector's evolution. This study employs a backcasting methodology - working backwards from a desired 2050 end state—to identify the enabling actions, governance models, and knowledge mechanisms required today.

## Methodology / Approach

A backcasting approach was employed to construct a Vision 2050 scenario, starting from a desired end-state and tracing backwards to identify the policy, technological, and behavioural changes required. The circular trust building (CTB) project, a European Union Interreg NorthSea consortium of six regions, was a platform for conducting workshops, surveys, and expert validation. Expert consultations involving representatives from public authorities, industry, and research institutions were conducted to refine assumptions and validate critical milestones. The EU level(s) framework was applied to link sustainability indicators with practical performance metrics, ensuring methodological consistency across environmental, economic, and social dimensions.

**Survey:** The survey employed a structured, mixed-methods design to explore how construction sector stakeholders understand circularity and which barriers and enablers shape progress toward a 2050 climate-neutral vision. Respondents from across the value chain (e.g., clients, designers, contractors, manufacturers, public authorities) completed an online questionnaire.

**Backcasting Workshop:** A multi-stakeholder workshop followed a classic backcasting sequence—defining a shared desirable 2050 future and retroactively identifying the milestones, policy reforms, and technological changes needed to achieve it. Participants included representatives from government agencies (planning, environment, and infrastructure), industry associations, large contractors, architects, and research organizations.

**Expert Consultation:** Following the participatory phase, expert consultations were conducted during the CTB consortium partnership meetings, which included regional specialists in sustainable construction, policy makers, and institutes. The consultations held as workshops aimed to verify the results of the survey and the backcasting workshops to assess feasibility and prioritise short-term to long-term interventions based on their impacts and achievability. Moreover, to translate the qualitative foresights findings into meaningful indicators,

the experts mapped outcomes into the LEVEL(s) macro-objectives. This was intended to connect long-term circularity targets to existing European performance metrics.

## **Results / Findings**

Participants identified an integrated 2050 vision encompassing whole-life carbon neutrality, material circularity, digital traceability, and social value creation. Key enablers were pronounced in the backcasting workshops, including policy harmonization across governance levels, mandatory circular procurement, adoption of digital product passports, innovation funding mechanisms, and standardized life-cycle indicators. In addition, principal barriers pointed out through the questionnaire survey were found to vary in these regions. These included fragmented regulation, lack of data interoperability, limited access to quality secondary materials, and cultural resistance to material reuse. By mapping these enablers and constraints onto LEVEL(s) indicators, the study identified leverage points where EU-wide measurement frameworks can reinforce national and sectoral governance mechanisms. For instance, coupling whole-life carbon (macro-objective 1) with resource use (macro-objective 2) enables coherent policy tracking of both decarbonization and circularity progress.

## **Discussion**

The backcasting process demonstrated that technical solutions already exist, but governance and market structures lag behind. It also revealed that decarbonization and circularity are mutually reinforcing rather than competing agendas: circular design strategies significantly lower embodied emissions, while carbon pricing mechanisms incentivize efficient resource use. Expert feedback emphasized the importance of aligning the current linear construction business models with circular business models, to enable appropriate transition from short to long term circularity transitions. The key proposals included making the marketplace for secondary materials visible to the stakeholders, integrating extended producer responsibility in national policies, establishing take-back schemes to ensure resale and remanufacturing of products and materials, developing digital tracking technology to trace material flow, and encourage design of disassembly.

## **/ Conclusion**

The combined use of surveys, backcasting workshops, and expert consultation with LEVEL(s) provides a robust methodological foundation for aligning construction-sector transformation with EU climate neutrality objectives. The study highlights the need for integrated monitoring frameworks and cross-sector collaboration to turn the Vision 2050 scenario into appropriate policymaking with supportive circular business models.

*Keywords:* backcasting, questionnaire survey, stakeholder perspective, circular transition, policymaking

## **Actors and interdependencies in sustainable entrepreneurial ecosystems fostering local food start-ups: Insights from urban areas in Western Germany**

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### **Introduction**

In recent decades, regional economic development policies have placed significant emphasis on the promotion of entrepreneurship as a means to stimulate growth, innovation, and value creation. Concepts such as entrepreneurial ecosystems (EEs) have gained popularity among academics and policymakers as a useful framework for understanding the interdependent contextual factors that support these growth-oriented entrepreneurship in cities and regions (Fritsch 2013, Stam & van de Ven 2021). Despite the valuable insights they provide into how regional configurations of actors, institutions, and resources foster firm creation and economic performance, little attention has been paid to the relationship between EEs and sustainable entrepreneurship, which is essential for addressing societal and environmental challenges such as climate change, environmental pollution, food waste, and inequality in the transition to a more sustainable and circular economy (Cohen 2006, Krebs et al. 2023, Simatupang et al. 2015). In this context, social enterprises and impact start-ups have emerged as key actors in linking economic activity with social and ecological value creation (Krebs et al. 2023 or Schneidewind 2018). Originating largely from civil society and activist movements, these enterprises are increasingly operating within real market settings while pursuing objectives that diverge from conventional market logic. Despite a growing political and academic recognition of their transformative potential and potential key role in driving systemic change, social enterprises face structural disadvantages in capital-driven economic systems, including limited access to finance, tailored support structures, and institutional recognition (Schmid 2020, Schneidewind 2018).

This contribution is associated with the recent wave of research on so-called sustainable entrepreneurial ecosystems (SEEs). The objective of the present case study emerges from the circumstances that, due to differing goals, activities, and obstacles, traditional EE-findings fit social entrepreneurs only to a limited extent. Recent studies, both theoretical and empirical, demonstrate that social entrepreneurs are more reliant on conducive local frameworks, networks, and cooperative relationships than traditional start-ups (Bischoff 2021, DiVito & Ingen-Housz 2021, Krebs et al. 2023, O'Shea et al. 2021). These findings indicate that sustainable entrepreneurial ecosystems frequently operate within their local context, thereby providing instrumental support to companies seeking to implement sustainable business ideas on a broader scale.

The present paper aims to analyse the importance of actors and their interdependence in urban entrepreneurial ecosystems supporting social enterprises in their inception and growth. In order to do so, it will focus on the still limited empirical evidence on the complex role and interdependencies of actors within such ecosystems, especially based on local cases in European cities. In an effort to further refine the research aim, the following sub-questions have been added:

- 1) Which actors are part of a sustainable entrepreneurial ecosystem and what role(s) do they play to directly and/or indirectly support impact start-ups?
- 2) How are the actors interconnected with one another and with key elements of the entrepreneurial ecosystem and which factors enable or constrain their interactions?

Building on these insights, the study aims to identify pathways for enhancing the transformative capacity of both individual actors and the ecosystem as a whole to support and promote impact start-ups and therefore foster local/urban resilience and socio-ecological transformation. The potential benefits of urban and local food production in enhancing productivity, sustainability, resilience, and adaptation to climate change are increasingly recognised (Bathen et al. 2019, Brandt et al. 2017 or Schneidewind 2018), and are complemented by the well-documented advantages of shorter distances and more localised material cycles (e.g., Angstmann et al. 2025). Building on these observations, this case study examines the entrepreneurial ecosystem that supports impact start-ups focused on urban food production in Cologne, Germany.

## Methodology / Approach

The present study examines the composition of an SEE in supporting impact start-ups and demonstrates which actors and interdependencies are particularly important for young impact start-ups and support their business activities. Concentrating on impact start-ups in the regional food sector in Cologne, Germany, the research combines the theoretical EE framework with the transdisciplinary method of constellation analysis to establish the position, importance, and functions of the individual actors. In order to gain these insights, the first step involves a secondary analysis of interviews with 15 impact start-ups in the Rhineland Region (from 2023). This analysis leads to an extending mapping of an initial constellation that contains possible actors, stakeholders, relations, and potential enabling or inhibiting factors in a sustainable entrepreneurial ecosystem. In the second methodical step, this constellation was utilised as a foundation for in-depth constellation-based dialogues with three entrepreneurs and seven ecosystem stakeholders. Each conversation culminated in the creation of a new constellation, incorporating the unique perspective of the individual participants on the SEE for impact food start-ups in Cologne. The final step involves merging the result of all ten conversations to create a final constellation. This approach allows detailed insights into how actors interact, which support functions they perform, and where enabling or constraining dynamics emerge.

## Results / Findings

The final constellation reveals a closely intertwined, diverse ecosystem comprising a wide variety of actors that support impact start-ups through their actions, both directly and indirectly. The principal finding of this study is that different start-up types appear to have distinct needs and, consequently, a different range of actors in their support network.

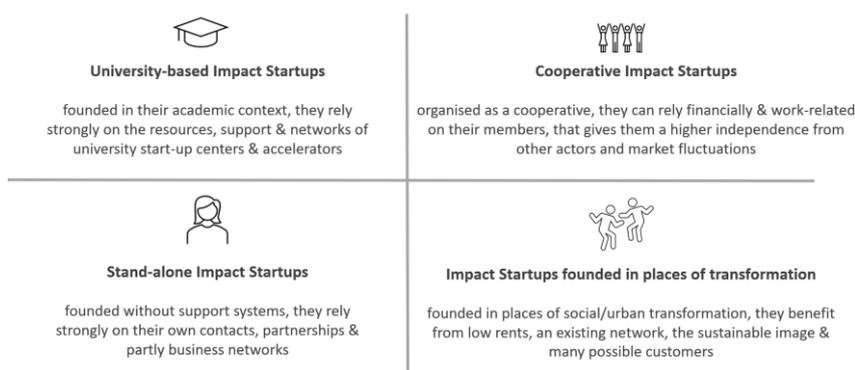


Figure 1 Differing needs and actors for certain start-up types (own figure)

In addition to the discrepancies in the composition and significance of actors (see figure 1), the study yielded several noteworthy cross-cutting findings. Firstly, it is apparent that impact start-ups rely on a strong and wide-based network with various actors that fulfil different functions within the ecosystem, ranging from “traditional” EE-actors such as financial actors, universities, or start-up accelerators to the crucial role of civic actors and impact multiplier in establishing network and support structures as well as promoting social

entrepreneurship and sustainable development both at the local and national level. The results also demonstrate the profoundly beneficial impact of mutual (sustainability-oriented) values and a high level of willingness to cooperate, resulting in a wide range of interactions and support systems. Conversely, other factors that appear conducive to fostering support for start-ups and facilitating interactions among relevant actors can be attributed to the integration of circular economy approaches. Such approaches encompass the deliberate sharing of resources, which in turn fosters the emergence of regional and urban cooperation between start-ups and various actors, including industrial factories and local gastronomy. Another significant promoter can be delineated by the intrinsic approach of urban production, enabling a multitude of synergies with local actors and other entrepreneurs while establishing short supply chains. Notwithstanding the presence of these drivers, a number of key hindering factors are to be considered, including fundamental issues such as low levels of political support and funding for impact start-ups or, in the context of prevailing economic crises, a minimal interaction between larger companies and start-ups.

## Discussion / Conclusion

By integrating multiple perspectives and knowledge bases, this study advances a more nuanced understanding of SEEs as place-based infrastructures for socio-ecological innovation. The findings indicate that, due to their focus on sustainability and degrowth, impact start-ups demonstrate a greater reliance on a more extensive support system, encompassing a diverse range of stakeholders. These SEE-actors exhibit a high degree of interconnectedness, driven by shared values. Furthermore, they display a high degree of receptivity to collaborative endeavours and provide mutual support. In order to enhance effective cooperation and support within an urban sustainable entrepreneurial ecosystem, local policymakers can pursue a range of options to bundle knowledge, capacities and resources within the SEE more effectively. For example, those in positions of authority within both the local political system and the private sector have the power to accentuate the significance of pivotal aspects by providing substantial financial support for wide-acting multipliers, thereby amplifying the positive impact of such ecosystems. The findings also illustrate that tailored support networks and a strong local civic society are important prerequisites for business success and the fulfilment of the impact start-ups' sustainability missions. Overall, the case study's findings emphasise the pivotal role of local networks, political and financial support, and cross-sectoral collaboration for fostering resilient, sustainability-oriented entrepreneurship in urban contexts, thereby providing pertinent insights for urban resilience strategies and climate adaptation policies.

**Keywords:** Sustainable Entrepreneurial Ecosystems, Constellation Analysis, Social Entrepreneurship, Urban Production, Impact Start-ups

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## **Pre-study for Energy Audit of Vida Arena**

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### **Introduction**

Ice skating and ice hockey are important parts of Swedish culture. Historically, these activities have been performed outdoors on naturally frozen ice surfaces such as lakes, but after the invention of refrigeration, artificially frozen indoor rinks were made possible. Large hockey arenas exist in many Swedish cities, with Växjö Lakers' Vida Arena in Växjö being one such example. These are complex from an energy perspective, with the core function of the facility being powered by large vapor-compression refrigerators, and the special climate inside placing high demands on space heating, ventilation and dehumidification to create a comfortable environment for players and audience and to avoid fog and condensation.

The EU's Energy Efficiency Directive (EED) requires, among other things, member states to enact legislation obligating large companies to perform energy audits every four years. Large companies will from 2026 onward be defined as companies with an energy use exceeding 10 Terajoules, or 2.8 GWh annually, a change from the previous definition of 250 employees and an annual turnover of 50 million Euro. Växjö Lakers, with an annual energy consumption of around 6.4 GWh comfortably fits within this new definition.

This project is a brief pre-study which aims to help a future official energy audit of Växjö Lakers' operations. It is conducted under the Center for Energy and Environment (CEE) project which aims to assist SMEs in the region with energy efficiency and sustainable building methods.

### **Methodology / Approach**

The project has been conducted in four parts:

- Visiting the facilities and examining schematics of the facilities and their energy systems to create an understanding of their operation and functions.
- Studying literature on energy audits and ice hockey arenas for information on best practice for energy auditing and on which parts of an ice hockey arena are typically problematic from an energy perspective.
- Analysing data from continuous sub-meters for parts of the facilities or specific equipment in order to chart the distribution of energy use and to find trends or interesting data points worth investigating in more detail.
- Contacting other organizations responsible for similar ice hockey arenas in Sweden and asking them if and how they have conducted energy audits or other energy efficiency activities.

## **Results / Findings**

The arena includes three ice rinks powered by two refrigerators, as well as a gym, restaurant and office areas. The ice rinks are frozen for about 42 weeks a year, with a break during summer. Solar panels are installed on the roof which produce roughly 340 MWh of electricity annually. Typically, the main energy consumers in a hockey arena are refrigeration, space heating, ventilation, dehumidification and lighting.

Analysis of the data largely confirms this is true in this case as well, with refrigeration and space heating representing approximately 23% and 35% of the total energy use respectively, space heating is done via district heating. Accurate submetering is currently unavailable for ventilation, dehumidification and lighting, and estimating their energy use in some way will likely be necessary for a proper energy audit. Domestic hot water (DHW) is also a significant energy user, representing roughly 10% of district heating use, though it is unknown how much of the DHW is heated using district heating, heat recovery from refrigerators and electricity.

Dehumidification is very important in ice hockey arenas, and is often performed inefficiently, with unnecessarily high energy use during the winter months when the need for dehumidification is relatively low. It is unknown if this is the case here, but there is some evidence that it might be.

Of the three ice rinks, the oldest and smallest one has a disproportionately high specific energy use compared to the other ones.

Other arenas have implemented, or are in the process of implementing, energy efficiency measures including improvements to heat recovery from refrigerators, switch to variable frequency drive pumps, switch to LED lighting and improved needs-based regulation for refrigeration, ventilation and lighting.

## **Discussion / Conclusion**

Due to the limited scope of the project, no actual suggestions for energy efficiency measures can be made, only suggestions for future work and identification of areas to investigate further. These include better submetering for some areas, especially ventilation and dehumidification. Where submetering is impractical, most likely for lighting, some other way of measuring energy use will likely be necessary. The reason for the smallest ice rink's disproportionately high energy use should be investigated and improved if possible. The current control systems for refrigerators in general, HVAC, dehumidification and lighting should be investigated and if possible improved to better align with the needs of the operation.

As this is only a pre-study not performed by certified energy auditors, there is much work to be done on an energy audit compliant with standards EN-16247 or ISO 50002 and Swedish legislation. Energy performance indicators should be decided upon, calculated and followed up after any energy efficiency measures. Perhaps most importantly, a list of specific energy performance improvement actions (EPIA) needs to be created after investigating which ones are possible to implement, with the projected performance of each one deciding how they should be ranked in the list.

*Keywords:* Energy efficiency, Energy auditing, Buildings, Ice hockey

## **Innovative Dimensions of Karim Najar’s Vertical Forest Design: Structural, Economic, and Ecological Perspectives for Sustainable Architecture**

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### **Abstract**

Vertical forests represent one of the most ambitious intersections between architecture and ecology, aiming to integrate vegetation directly into urban structures. While international projects such as Milan’s Bosco Verticale have demonstrated the ecological and aesthetic potential of vertical forests, they have also revealed critical limitations related to cost, maintenance, and structural demands. This paper explores the innovative dimension of architect Karim Najar’s vertical forest design, with focus on both structural/economic solutions and ecosystem services contributions. Findings from Stina Lindberg’s thesis in Karlstad highlight the economic and structural feasibility of Column-attached container planting system, while the work of Emma Nikitin and Tadas Plekavicius provides an ecosystem services framework for evaluating vertical forests in residential contexts. By combining these insights, the paper demonstrates that Najar’s vertical forest offers not only an economically viable construction paradigm but also measurable ecological and social co-benefits. This positions the design as a scalable model for sustainable cities seeking climate resilience and biodiversity integration.

*Keywords:* Vertical Forests, Sustainable Architecture, Ecosystem Services, Structural and Economic Feasibility, Climate Resilience and Biodiversity

